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AIMS AND SCOPE

ISRM (India) Journal is a half yearly journal of the Indian National Group of International Society for Rock Mechanics (ISRM), which is involved in dissemination of information on rock mechanics, and its related activities in the field of foundation and abutments of dams, tunnel engineering, mining, underground works, rock slope stability, road works, etc.

The aim of the journal is to encourage exchange of ideas and information between rock mechanics practitioners worldwide. The journal provides an information service to all concerned with Rock Mechanics about the development of techniques, new trends, with a view to enable updating of knowledge. The original manuscripts that enhance the level of research and contribute new developments to the Rock Mechanics are encouraged. The journal is expected to provide useful information to researchers, technologist and policy makers in the key sector of Water Resources, Infrastructure Development (including underground works), Hydro Power, Mining and Petroleum Engineering, etc. The Journal has both print and online versions. Being peer-reviewed, the journal publishes original research reports, review papers and communications screened by the Editorial Board, consisting of renowned experts.

The manuscripts must be unpublished and should not have been submitted for publication elsewhere. **There are no Publication Charges.**

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INDIAN NATIONAL GROUP OF ISRM

ISRM (INDIA) JOURNAL

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FROM THE EDITOR'S DESK



First of all, I take this opportunity to wish all the readers a Very Happy and Prosperous New Year.

Considerable activities in India in the field of rock mechanics are in progress, mainly due to the execution of projects for water resources development for irrigation, flood control and hydro power generation, building of roads in mountainous areas, sub-surface excavations for under-ground railway, storage and mining purposes, etc.

Constructions of dams, tunnels, underground works, open pit mining, deep underground mining, rock slope stability are the works necessitated for the aforesaid structures.

Development of these structures often encounter problems associated with unfavourable geological conditions. How these problems have been dealt successfully is what we should all share. The experience gained during construction of these works will help in understanding the mechanism or rock support interaction, thus advancing the frontiers of rock mechanics.

From the year 2013, Indian National Group has planned an International Symposium on "Rock Mechanics" every year to deliberate on the advances in rock engineering. The first event under the series "Rock Mechanics India'2013- Present Technology and Future Challenges" will be held in August 2013 in New Delhi. I hope that the deliberations at the symposium will help in formulating appropriate measures needed for successful execution of projects whether they relate to mining, tunnelling, underground cavern or metro. I invite all concerned to actively participate in the Symposium.

I thank all the authors for their contributions to this issue. I thank the members of the Editorial Board for sparing their valuable time to review the papers and offer their comments/suggestions to improve the contents of the articles.

The fee back from all the quarters has given us the encouragement to our initiative and I request all the readers and their colleagues/fellow professionals to contribute technical papers/case studies to further improve the utility of the Journal.

A handwritten signature in black ink, appearing to read 'V.K. Kanjlia', with a horizontal line underneath.

V.K. Kanjlia

Editor and Member Secretary
Indian National Group of ISRM

MESSAGE



At the outset, as President of the International Society for Rock Mechanics (India), I would like to convey my Hearty Greetings and Best Wishes for a very Healthy, Happy, Prosperous and Successful New Year – 2013 to all the Members of the ISRM (India) and all Subscribers/ Readers of the ISRM (India) Journal. I would also like to convey my Greetings and High Appreciation to all the Members of the Editorial Board.

Rock Mechanics is the theoretical and the applied science of the mechanical behaviour of Rock and Rock Masses. The present state of knowledge permits only limited correlations between theoretical predictions and empirical results. The most useful principles are based upon data obtained from laboratory and in-situ measurements and prototype behaviour. Rock Mechanics is one of the main fields of interest in Hydro Power Development, Infrastructure Development, Mining etc. Rock Mechanics is becoming increasingly important in many more branches, the most significant globally being the disposal of hazardous radioactive waste in deeply located repositories. It is an interdisciplinary engineering science requiring interaction between the Physics, Mathematics, Geology, Civil, Petroleum and Mining Engineering. Collaboration among disciplines offers the best hope for success in dealing with the present and future problems related to Rock Mechanics. Our Editorial Board is designed to include researchers with inter-disciplinary expertise at International level in addition to researchers with expertise in the relevant disciplines.

The main aim of the Journal is to disseminate the development of techniques, new trends, experience gained by others to enable updating the knowledge of Rock Mechanics.

The Journal is published Half Yearly and available in both print and online versions The First Issue of the Half Yearly Technical Journal ISRM (India) was brought out in January 2012. The quality of contents and printing has been very good. However, there is always a scope to improve and excel.

I would request all the readers to offer their valuable comments and suggestions to enable us to improve the quality and the utility of the Journal.

Dr. H R Sharma
President, ISRM (India)
&
Chief Technical Principal – Hydro
Tractebel Engineering Pvt. Ltd.

ROLE OF GEOLOGY AND SPECIAL ROCK MECHANICS TESTS IN TBM TUNNELLING – A PERSPECTIVE

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ABSTRACT

A growing need to switch over to the clean sources of energy, such as hydropower, is being felt in India after burning much of our coal reserves to an alarming stage. Incidentally, India has been gifted with numerous perennial rivers originating from the great Himalayas favoring hydropower generation. However, these young folded mountains with an extremely variant geology created several problematic situations delaying many tunnelling projects.

The major construction work of any hydro power project is the construction of head race tunnel (HRT) which had made use tunnel boring machine popularly known as TBM. There are number of ongoing projects of NHPC Ltd and NTPC Ltd such as Parbati Stage II and Tapovan-Vishnugad project, etc. deploying TBMs for tunnelling. As huge amount of money is involved in deploying TBM, it is important that it should successfully complete the project. Thus, suitability of TBM needs to be established with the help of various geological and geophysical investigations coupled with insitu and laboratory tests. The role of geology, uncertainties involved and consequent hazards have an immense influence on the operational success of TBM and hence need attention.

TBM performance prediction models, namely, NTH, CSM, RMI-NTH & QTBM, are frequently used owing to their increased popularity over the years. RMI- NTH model is an empirical performance prediction method based on historical field performance of machine in certain rock types. Empirical graphs and equations obtained from regression analysis between rock properties, ground condition, machine parameters and rate of penetration are used in this. The CSM model on the other hand involves starting from the individual cutter forces and determines the overall thrust, torque and power requirement of the entire cutter head.

This paper discusses the geological problems encountered while driving tunnels with TBM, specially, with respect to Indian conditions. Different types of specialized rock mechanics tests that are carried out and available at Indian School of Mines, Dhanbad for enabling the selection of TBMs are also presented alongwith some results. Typical performance achievable in a given rock type is estimated using the RMI-NTH model. A case study of TBM driveage pertaining to Tapovan-Vishnugad Hydel project, NTPC Ltd. is considered for the analysis. The suggested approach with field corroboration could be useful for predicting the possible advance rate in a given formation.

Keywords: *Geological problems, mixed face conditions, rock mechanics tests, tunnel boring machine, head race tunnel, boreability prediction models*

1. INTRODUCTION

India has an immense hydropower potential to the tune of 84000 MW, a major chunk of which is in Himalayas. The surge in power demand in the country has necessitated putting an increased thrust in development of hydroelectric projects in India. The pace of tunnelling work, which forms a major component of hydroelectric development, has a notable bearing on the implementation of the project. Now while the focus is on faster completion of projects, need for advanced technology like TBM in tunnelling is required. But unfortunately TBM could not gain wider

acceptance in the country due to complexities involved in geological conditions, prevalent in India especially in Himalayas. The tectonically deformed jointed rock mass of Himalaya pose a major challenge to project planners. Although initial experience with TBM was not encouraging all efforts are on to make TBM successful in India.

Though TBM excavation is a very fast method tunnelling, it needs meticulous planning because in case of unpredicted/unfavourable conditions, the adverse effects of TBM in terms of time and cost are far more greater than conventional methods thus putting a huge investment at

risk. The experience suggests that many of the problems can be avoided if sufficient advance information ahead of the face is available. It is essential that detailed exploration work is carried out before the start of the project and exploration ahead of the face should be undertaken on a condition basis. Use of tunnel seismic profiler services can be roped in for predicting in advance the geological condition to be encountered (upto 200 m from the face).

The choice of TBM is another important aspect that needs an initial analysis at planning stage and no TBM can be designed for every type of geological condition that is encountered in tunnelling though due care can be exercised in minimising the operational problems with adequate rock testing programs both in laboratory and field. Thus, the design and special construction characteristics of each TBM need to be carefully designed project-specific for the successful completion in time.

The concept of tunnel boring machines is not new and its history dates back to the year 1846 in Italy. Since then there have been revolutionary improvements in this machine. Though it has completed many challenging projects in the field of road/railway tunnels, hydro power and different other utilities successfully but there are a number of cases where it has been proved to be a curse during the middle of the project. The TBM had got stuck in the mid way of the project due to various reasons, chiefly resulting from the varying geology of the stipulated project area, and thus creating huge financial losses to the contractor as well as undue delays in the project. India is bestowed with huge hydropower potential chiefly spread across Himalayas. Some of the TBM projects envisaged or already deploying TBMs are given in Table 1.

Table 1 : TBM projects envisaged in India (Dubey, 2008)

Hydro power projects	Power generated	Status of project
Chenab Basin (HP)	2500 MW	Identified
Tapovan vishnugad	520 MW	Under implementation
Rupsiabagar Khasiabara	261 MW	Under clearance
Amochu (Bhutan)	500 MW	Identified
Kolodyne (Mizoram)	460 MW	Identified
Etalin & Attunli(AP)	4500 MW	Identified

2. ROLE OF GEOLOGY IN TBM DEPLOYMENT

“For the geologist, the range of rock conditions is like a paradise but for the contractor, it is a nightmare,” by V. L. “Raja” Rajasekaran.

The geology along a tunnel alignment plays a dominant role in many of the major decisions that must be made in planning, designing, and constructing a tunnel. Geology dominates the feasibility, behaviour, and cost of any tunnel. Although difficult to appreciate, the engineering

properties of the geologic medium and the variations of these properties are as important as the properties of the concrete or steel used to construct the tunnel structure. In a tunnel, the ground acts not only as the loading mechanism, but also as the primary supporting medium. Thus, it is vital that the most appropriate geotechnical investigation is conducted early in the planning process for any tunnel. The more challenging the ground, the greater the pre-planning that is required before tunneling.

Some of the difficult ground conditions, which can affect TBM performance, are boreability limits, instability of the excavation walls, instability of the excavation face, fault zones and squeezing. Tunnel excavation by a TBM may encounter other difficult ground conditions as well due to the presence of clayey soil, soft ground resulting in settlement of the TBM, strong inflow of groundwater and gas, rock bursting, rock and water at high temperature and karstic cavities.

It has been shown many times that those tunnels that have been investigated more thoroughly have fewer cost overruns and fewer disputes during construction. The unanticipated problems are those that can create costly delays and disputes during tunnel construction. Detailed and thorough explorations must precede any tunneling activity more so in case of TBM technology so that they can help evaluate the feasibility, safety, design, and economics of a tunnel project.

2.1 Geological Uncertainties – Their Influence on Excavation by TBMs in India

Uncertainty means “lack of knowledge”. But still in many cases this problem may be resolved substantially by the methods of quantification or some other methods in which we can derive some useful information and reach to a decision. Uncertainty may be categorized in two ways,

1. Aleatoric Uncertainty (natural variability)
2. Epistemic (uncertainty due to ignorance)

The former refers to the distribution in the parameters that influence the behavior of the structure. This type of uncertainty cannot be reduced by extended measurement. The second type of uncertainty can be attributed to lack of knowledge. This includes insufficient knowledge of the actual geological condition including poor condition in terms of properties and geometries. This type of uncertainty can be reduced by obtaining more information, i.e., from investigation, monitoring and measurements (Palmstrom, 2010).

2.2 Reasons for Poor TBM Performance in Tunnelling – Some Geological Issues

In Indian scenario, it may be observed that almost all the hydro power projects are situated in the mountainous region i.e., Himalayas or sub-Himalayan tracts. Himalayas, being young folded mountains, are still undergoing changes and are subjected to intense

compression primarily due to continent-continent collision. This often resulted in numerous folds, faults, foliations and joints which are the common characteristic of these rocks raising stability concerns. The previous studies on TBM applications in India by Vishnoi in the year 2012 have revealed useful facts pertaining to the uncertainties found in the projects and the outcome (Table 2).

In a nut shell, the following are some of the prime causes of poor tunnelling rates achieved by TBMs in India:

- Intensely disturbed grounds
- Water seepage under high pressure leading to instability
- Supporting problems in shear zones sometimes associated with intense water ingress
- Squeezing ground
- Release of rock blocks due to blocky and jointed strata

- Rock bursts due to cover loads
- High geothermal gradients
- Cavity formation
- Hard and abrasive rocks leading to higher cutter consumption

Deploying a TBM for a project involves a huge investment and risk from the employer as well as contractors side. The unfavourable conditions can be produced by either a rock mass of very poor quality causing instability of the tunnel or a rock mass of very good quality (i.e. strong and massive rock mass) leading to very low penetration rates. Typical hazards associated alongwith the probability of occurrence and risk allocation are presented in Table 3. Some of the hazards associated with the TBM tunnelling are more frequent and thus need special attention apart from their allocation whether it is to the employer or the contractor.

Table 2 : TBM applications in India and the uncertainties encountered (Vishnoi, 2012)

Project	Location	Uncertainties	Outcome
Dulhasti Hydro Electric Project, NHPC Ltd.	Lesser Himalayas in Kishtwar district of Jammu & Kashmir, India	<ul style="list-style-type: none"> • Unfavourable geological conditions in the form of shear zones crossing the tunnel regularly with high seepages of water and incidences of roof collapse. • Tunnel's structural failure during construction. • TBM got buried. 	<ul style="list-style-type: none"> • Contractual complications Contractor refused to continue • High cost and time overrun
Koteshwar Hydro Electric Project, THDC	Middle Himalayas in Uttarakhand State, India.	<ul style="list-style-type: none"> • Unfavourable geological conditions in the form of slope failure at power house location during construction. • Major flood occurred at site during construction. • Diversion tunnel's structural failure during construction. • Contract rates became unviable. 	<ul style="list-style-type: none"> • Contractor started looking for claims rather than completing the works. • Proactive action by the Owner
Parbati Stage II Hydro Electric Project, NHPC Ltd.	Located in Kullu district of Himachal Pradesh, India	<ul style="list-style-type: none"> • Unfavourable geological conditions in the form of large underground water inflows. • TBM got buried 	<ul style="list-style-type: none"> • Contractor was not ready to share the unexpected Risk. • Inordinate delay in completion.
Tapovan- Vishnugad Hydro Electric Project, NTPC Ltd.	Uttarakhand, India.	<ul style="list-style-type: none"> • Excessive cutter wear due to abrasive rocks, • Unfavourable geological conditions in the form of heavy water ingress due to fault/ geological failures. 	<ul style="list-style-type: none"> • Contractor stopped the work and denied accepting the cost of risk. • Delayed construction

Table 3 : Typical hazards associated with TBM tunneling with relative probability of occurrence

Hazard	Probability of Occurrence	Risk Allocation
High water pressure	Medium	Employer
Swelling pressure	Medium	Employer
Stucking, clamping of TBM	Medium	Contractor
Face collapse by ground water flow	Medium	Contractor
Gas detection	Medium	Contractor
Overstressed lining by ground water pressure	Low	Contractor
Excavation material not transportable through conveyor belt	Medium	Contractor
Exceptional high wearing of excavation tools	High	Contractor
Boulders within soil formation	Medium	Contractor
Natural Caverns	Medium	Employer
Approaching fault zone	High	Contractor
Water inflow through segments	Medium	Contractor
Contaminated ground	Very Low	Contractor
Treatment of excavation material	Very low	Contractor
Thermal Impact	High	Contractor

2.3 Boreability Using TBMs

The TBM performance basically depends on the three variables, namely, penetration rate, machine utilization and cutter cost. The main index describing the capacity of a TBM to excavate a given rock is the penetration rate per revolution of the cutter head that the TBM is able to achieve under the maximum thrust. It is not possible to establish a limit of penetration per revolution below which a rock shall be considered non-boreable. Such a limit is also influenced by the abrasivity of the rock, the diameter of the tunnel, and the thickness of the rock formation. The high abrasivity, associated with low penetration, dictates frequent changes of cutters, increasing the cost for each cubic meter of rock excavated, in addition to the time lost in substituting the cutters. With increase in the tunnel diameter there are different effects which make the situation worse. It may, thus, be summarized that large variability in geology is the root cause of the problems leading to delays and elevated costs. Thus, considerable effort should be given at the initial stages of the project for conducting comprehensive and proper site investigation as the cost of such investigation is relatively low in comparison with the total contract sum. As for budgeting ITA recommends 2.5% to 3% of the estimated total contract value should spent on investigations

2.4 Mixed Face Conditions (MFC) and their Effect on TBM Performance

Hard rock tunnel boring machines (TBMs) have today reached a stage of development so that a tunnel can

be bored in practically any rock mass. However certain ground conditions still present considerable challenges for the economic application of the TBM method. "Mixed face conditions", shortened as MFC, is a term used when the tunnel face consists of atleast two rock types with completely different boreability – in simple terms a mix of soft and hard rock. It is a normal feature in hard rock tunnels. It causes well known problems with impacts to the cutters and increased loads to the cutter head structure and main bearing. An easily observable result is increased vibration. This result in reduced penetration rate, increased cutter breakage and other delays reduce the TBM utilisation. The effect of overall performance may be significant, especially if the MFC are pronounced and prevails over long tunnel section. Failure to predict or recognise MFC may cause selection of not suitable TBMs resulting in seriously reduced performance, which may lead to contractual claims (Blindheim and Nilsen, 2002).

The degree of MFC depends on both the mechanical properties of the geological formations and the geometry of such formations. In a horizontal tunnel a vertical dyke crossing the tunnel perpendicularly will normally not give much problems. As the geological formations are aligned more parallel o the tunnel axis, the situation becomes increasingly unfavourable. This is the case for instance in Icelandic basalt formations, as shown in Figure 1, where the different volcanic and sedimentary layers are usually dipping 2°-10°.

It is evident that a large part of a near horizontal tunnel in such geological conditions would be excavated in MFC. This could affect the boreability of the rock and

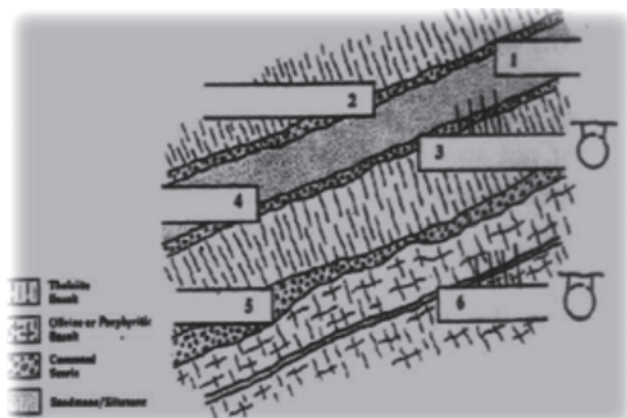


Fig. 1 : Mixed faced conditions often encountered in TBM tunnelling (Blindheim and Nilsen, 2002)

stability of the face. For explaining this several physical and mechanical parameters that are expressing the boreability may be relevant for describing MFC. For this Uniaxial compressive strength (UCS) is the parameter that often is put in focus in discussions concerning MFC. The UCS may not be the best parameter for TBM boreability, but its availability makes it a useful reference. Next parameter that used is Drilling Rate Index (DRI) may be more relevant as it includes the resistance to impacts, which simulates the dynamic loading of rock from the disc cutters. Further parameters include elasticity or abrasivity may also be of relevance to describe MFC.

2.4.1 Effects of MFC

The effects of MFC with respect to boreability are connected to impacts on the cutters, vibrations of the cutterhead and the TBM, uneven loading of the main bearing, and increased cutter breakage. The disc cutters experience a rapidly varying load from close to zero to peak loads of 5-10 times the average. If this hardness variation is sharp between two rocks, the cutter will experience an impact, rolling from the weaker into the stronger material, the average and peak loads also jump up to a higher level. If this impact is large, the cutter edges may chip or break. If the rocks are abrasive, the abrasive wear may also result as the contact stresses are increasing. Over time, the cutter bearings will take more and higher shock loads per revolution, and bearing breakage will occur more often. And if the bearing "freezes", the cutter ring will be destroyed as well. In total increased cutter consumption will result. The effect is TBM utilisation is reduced due to increased cutter change time, as well as increase of other scheduled and unscheduled stoppages.

2.4.2 Effects on TBM Operation

During operation of TBM if operator observes that the vibrations are increasing from the normal level to high level or if the TBM deviates due to uneven hardness his

immediate reaction will be to lower the applied thrust force to the cutter heads and to reduce the RPM. To which level the thrust and RPM should be reduced is influenced by many factors such as boreability of the rock and rock mass, the size of cutters, the type and age of the TBM, the length and expected conditions on the remaining drive, etc.

2.4.3 Dealing with MFC

MFC with different rock types would normally have less impact than a medium to very fractured rock mass. In fractured rocks, the rocks may fall out or pushed out of face leaving open gaps or voids. The voids left in the face will cause impacts when the cutters passing the voids hits the rock on the side of the void. In MFC cases with very high strength ratios say above 5-10, it may be necessary to reduce by 50%. This would obviously have a large impact on the overall performance.

2.5 Models for Predicting the TBM Performance

Two popular approaches for the calculation of TBM penetration are available though a few models are recently added to this. The most popular models are CSM and Rmi-NTH models. Input in the form of rock characteristics and machine parameters are provided and after numerous computations the output in the form of certain useful performance parameters is provided (Table 4).

3. ROCK MECHANICS TESTS VIS-A-VIS TBM SELECTION

It may be observed from the above-mentioned two TBM performance prediction models (Table 4) that several rock parameters are needed to be used as input parameters for the introduction of TBMs which are essentially obtained from both laboratory and field investigations. Considering this need relevant test setup was created at Indian School of Mines, Dhanbad and tests are being carried out since 2001. The following sections present the rock mechanics tests required to be carried out for TBM selection, design and operation (Murthy et al, 2005).

• Brittleness Index (BI)

The brittleness value S_{20} is an indirect expression of the necessary amount of energy it takes to crush the rock. About 500 gm crushed rock sample (based on the density of rock) between 16 and 11.2 mm sieve size is taken and pounded with a 14 kg weight from a height of 25 cm for 20 times. The BI value is the percentage of the material that passes the 11.2 mm sieve after 20 drops and is determined as the mean value of 3 to 4 parallel tests. Higher the brittleness better is the relative boreability.

Table 4 : Parameters used in CSM and NTH models for TBM design (Palmström, A.1995, Bruland 1998)

CSM MODEL		RMI-NTH MODEL	
Parameters	units	Parameters	units
INPUT			
Cutter radius	(in)	Fracturing	Class(0-iv)
Tip width	(in)	Brittleness	S20 Index
Spacing	(in)	Drillability	Sievers 'J' index
Penetration	(in)	Abrasiveness	AV index
Rock UCS	(psi)	Porosity	%
Tensile Strength	(psi)	Cutter Dia	mm
TBM Diameter	(ft)	Cutter Load	kN
RPM	(rev/min)	Spacing	mm
No. of Cutters	(#)	Machine Diameter	m
OUTPUT			
Thrust	(lbs)		
Torque	(ft-lbs)		
Power	(hp)		
Cutting Force	(lbs)	No. of Cutters	#
Normal- Thrust	(lbs)	RPM	rev/min
Rolling/Torque	(lbs/ft-lbs)	Thrust	Ton
Power	(hp)	Power	kW
Basic Penetration	(in/rev)	Basic Penetration	mm/Hr
Rate of Penetration	(ft/hr)	Rate of Penetration	m/Hr
Head Balance	(force/moments)	Torque	(kN-m)
Machine Specification	(th,tq,hp,etc)	Utilization	%
Performance Curve	(Graph(rop-vs-th tq vs ts)	Advance Rate	(m/Day)
Utilization Curve	(%)	Cutter life	(Hr/Cutter)
Advance rate	(Ft/day)		
Cutter life	(Hr/cutter)		

• Sj Value

The Seiver's J value expresses indirectly the surface hardness of the rock. The hole depth measured in 10^{-1} mm units after 200 revolution by the miniature drill with thrust of 20 kg is known as Sj value. The drill bit used is 8.5 mm in width with 110° bevel angle. Higher the Sj value better is the boreability.

• Drilling Rate Index

The DRI values are obtained using a nomogram shown in Figure 3.d. Higher the DRI better is the boreability.

• Cerchar Abrasivity Index

Abrasiveness is one of the properties of rocks that is measured in order to assess their suitability for mechanical excavation. This parameter has been found to strongly govern the performance of disc cutters, their rate of replacement and therefore the cost of the tunneling. The test is conducted by abrading a steel pin under a

static load of 7 kg by moving the pin 1 cm on the rock in 1 sec. The pin is machined from steel having a tensile strength of 2 kN/mm² (Rockwell hardness 54-56). The pin is shaped to have a sharp 90° conical point. After each abrasion test the wear flat on the end of the pin is measured using a microscope equipped with a length scale. The average diameter of the wear flat, measured in 10^{-1} mm units gives the The Cerchar Abrasivity Index. The scale ranges from 0 to 6, one-index point corresponding to a conic blunt surface diameter of 0.1 mm. Rocks with an abrasiveness value greater than 4 may give rise to high rates of wear on TBM cutters.

• Uniaxial Compressive Strength

The uniaxial compressive strength of rock samples is determined using a stiff testing machine (servo controlled) under controlled loading rate. Tests are carried out as per the norms laid down for testing in ISRM suggested methods.

• Brazilian Tensile Strength

The tensile strength of rock is determined using Brazilian method. Both parallel and perpendicular to foliation are determined so as to fix the cutters to take this advantage. Values are higher when the samples are loaded perpendicular to foliations.

• Young's Modulus of Elasticity & Poisson's Ratio

The Young's Modulus of elasticity (tangent) was measured in MTS stiff testing machine using strain gauges (balanced). The data were acquired by a data acquisition system (SPIDER 8).

• Thin section analysis

Mineralogical studies were also done to understand the hard minerals present alongwith their texture, orientation etc. Microphotographs of two rock types are shown in Figure 2 a & 2b.

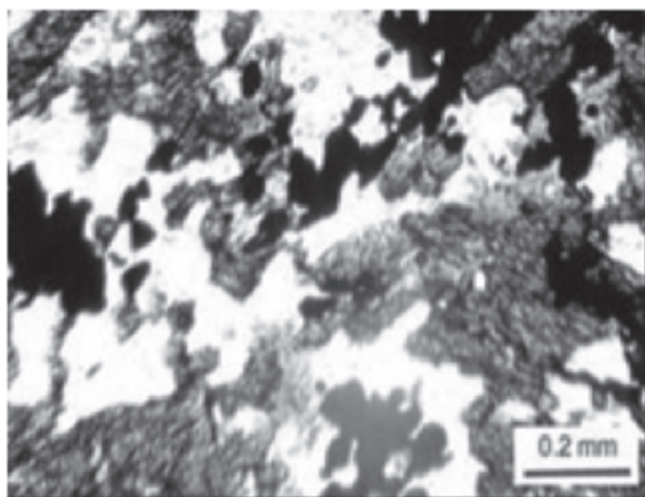


Fig. 2a : Thin Section of Metabasic rock

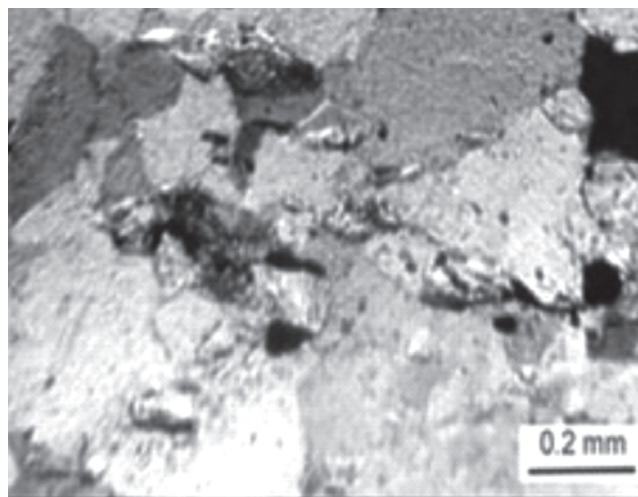
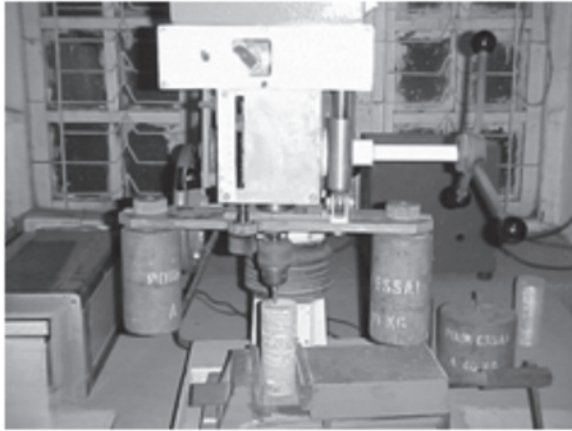


Fig. 2b : Thin Section of Quartzite

Different test setup and the results on different rock suits supplied from Tapovan-Vishnugad project are provided in Figure 3 and Table 5 respectively.

Table 5 : Rock properties of different rock suits, Tapovan-Vishnugad Hydel Project (Murthy, 2005)

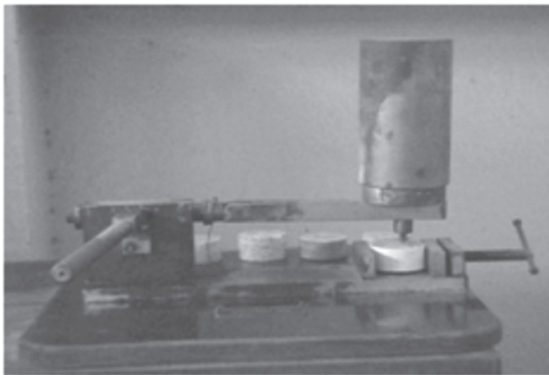
Name of rock	BI	Sj	DRI	CAI	UCS (MPa)	BTS (MPa)	MOE (GPa)	Poisson's Ratio
Metabasic rock	69.5	53.2	79	2.40	84 (52-107)	6.7-8.3	7.8 (5.8-9.5)	0.26 (0.16-0.33)
Augen Gneiss	52.4	31	58	3.42	91 (61-125)	8.4-8.7	27.9 (24-29)	0.23 (0.18-0.30)
Coarse grained Gneiss	63.2	28.6	69	4.35	77 (63-88)	7.3-7.9	35 (23-48)	0.27 (0.10-0.40)
Foliated Gneiss	63.5	5.5	62	3.50	98 (84-114)	7.3-10.1	36.7 (34-40)	0.24 (0.17-0.34)
Fine grained Gneiss	58.7	16	61	3.00	196 (143-236)	6.9-8.4	36.1 (29-42)	0.14 (0.11-0.16)
Quartzite	55.6	3.83	52	5.62	184 (103-254)	7.8-8.7	55.5 (45-63)	0.16 (0.15-0.18)
Mica Schist	70.3	107.5	86	2.28	Regular core sample could not be obtained			



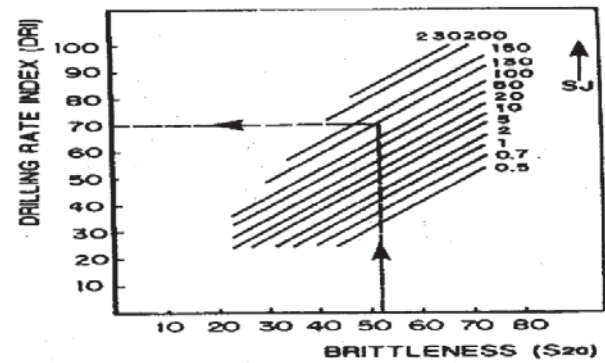
(a) Siever's J value (Sj)



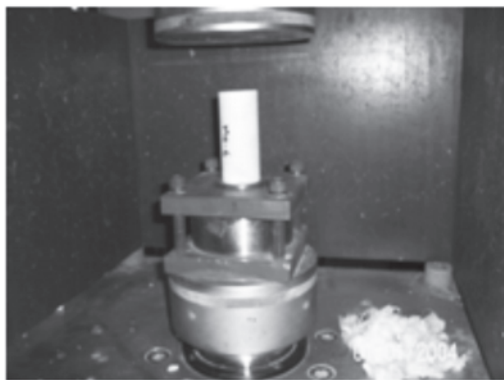
(b) Brittleness index (BI)



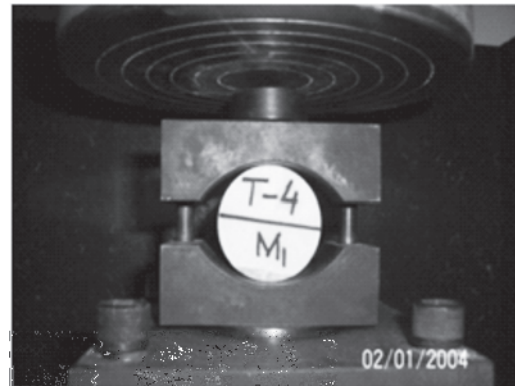
(c) Cerchar Abrasivity Index (CAI)



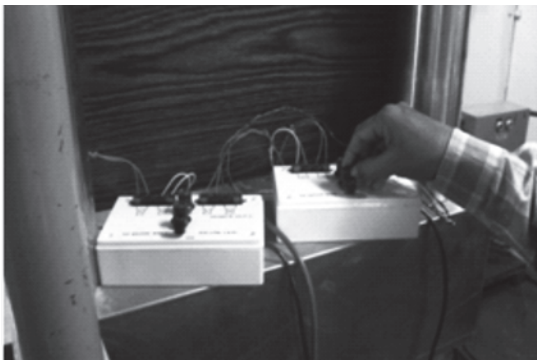
(d) Nomogram for estimation of DRI



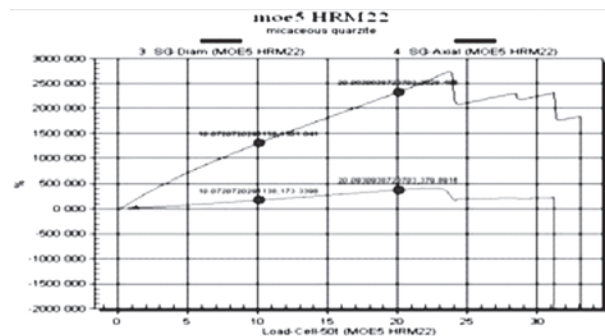
(e) Uniaxial Compressive strength



(f) Brazilian Tensile Strength



(g) Setup for the determination of Young Modulus



(h) Analysis for computing MOE and Poisson's Ratio

Fig. 3 : Laboratory test setup for TBM application, ISM, Dhanbad

4. PERFORMANCE PREDICTION OF TBM

TBM is in operation in Tapovan-Vishnugad Hydel Project of NTPC Ltd. The TBM adit between Ch. 130.00 and 371.08 m was excavated by a double shielded tunnel-boring machine (Figure 4). The rock mass was observed from the muck either on the conveyor belt or in the dumping yard, through the holes for pea gravel, grouting and erector in the precast segments, in front of the cutter head and through the telescopic shield. The rock mass in TBM adit are predominantly quartz mica gneiss with mica schist and quartzite bands, and quartzite (Joshimath Formation), which are highly to slightly weathered and / or disintegrated (Weathering grade: W3 to W1).

The rock mass is characterized by prominent two or more joint sets and few random joints with silty or sandy-clay coatings and small clay fraction (non-softening), and non-softening minerals, sandy particles, and clay-free disintegrated rocks, etc. along them. The rock mass is completely dry in general and wet at some places. Judging from the total thrust force of the cylinders, which lies mostly below 5000 kN, the rock mass condition appears to be poor to fair. Based on the estimated Q-values, permanent rock support (a combination of rock bolts, steel fiber reinforced shotcrete and steel ribs) was recommended for HRT. (Adhikari et al., 2009).

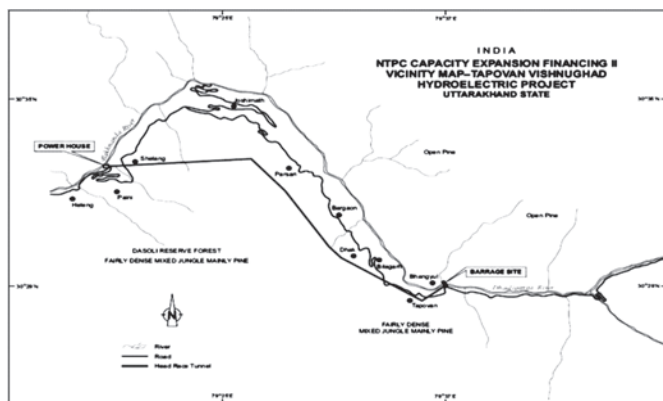


Fig. 4 : Layout of the HRT, Tapovan-Vishnugad Hydel Project, NTPC Ltd. (Murthy, 2005)

The headrace tunnel driven using TBM at Tapovan-Vishnugad Hydro Power Project would intersect, mainly, medium to high grade metamorphic rocks. The project area forming a part of Dhauliganga and Alakhnanda valley exposes rock classed as central Himalayan crystalline. The tunnel is proposed to be driven by Tunnel boring machine (TBM.) to negotiate the high cover reach. The length of the tunnel to be bored by TBM from Dhauliganga to Alakhnanda would be around 11.975 kms, and likely to cover Metabasic rock, Augen Gneiss, Coarse grained Gneiss, Foliated Gneiss, Fine Grained Gneiss, Quartzite and Mica schist formations throughout its length. The TBM specifications used are provided in Table 6.

Table 6 : TBM specifications used in Tapovan-Vishnugad Hydel Project, NTPC Ltd. (S.K. Sengupta, 2008)

Machine parameters	Value
Model	Herrenknecht's double shield hard rock TBM
Front shield dia	6480 mm
Cutter head	6550 mm
Disc cutters(54 nos)	432 mm(17")
Max thrust per cutter ring	267 kN
Max recommended cutter-head thrust	14,418 kN
Cutter head power	6x350 KW
Max torque	4590 kNm
Gripping force by grippers(2 nos)	2x18465 kN
Cutter Tip width	19.05 mm

4.1 Estimation of Penetration Rate

The basic penetration can be estimated, for a given gross thrust per disc and cutter diameter, from the study conducted by Movinkel & Johannessen in 1986 (Figure 5).

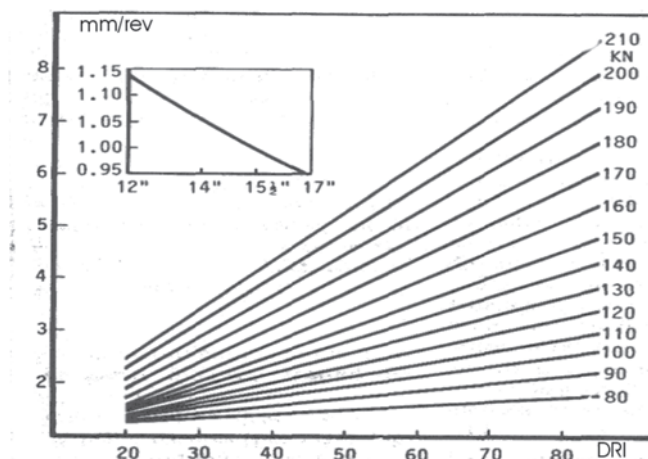


Fig. 5 : Basic penetration as a function of DRI, (from Movinkel and Johannessen, 1986)

From the above suggested method, for a DRI value of 52 and gross thrust per cutter at 210 kN, the penetration can be found as 5.32 mm/rev. For a thrust of 267 kN (for the TBM being used in Tapovan), this could well be extrapolated close to 9 mm/rev. Considering the limitation of the above approach for higher thrust values, the RMI-NTH model has been used for estimating the basic penetration.

The RMI-NTH model, for estimating the daily advance of TBM for HRT driven in Parbati Stage II TBM tunneling, was presented earlier (Murthy et al, 2011). According to the RMI-NTH Model, the instantaneous penetration rate is given by the following relation, and the unit is mm per revolution.

$$I_o = (M_{EQ}/M_1)^b \quad \dots(1)$$

where, M_{EQ} represents the TBM properties, and ' M_1 ' and ' b ' depends on the rock mass properties. The rock mass properties are in turn represented by the factor ' K_{EQ} '.

The value of ' M_{EQ} ' and ' K_{EQ} ' can be determined by the relations (equation 2 & 3) given below:

$$M_{EQ} = M_B \times K_D \times K_A = 267 \times 1.15 \times 1.02 = 313.2 \text{ kN} \quad \dots(2)$$

$$K_{EQ} = K_S \times K_{DRI} \times K_{POR} = 1.0 \times 1.04 \times 1.02 = 1.06 \quad \dots(3)$$

Where,

M_B is applied thrust per disc (in kN),

K_D is the correction factor for cutter diameter, (refer Fig. 6)

K_A is the correction factor for cutter spacing, (refer Fig. 7)

K_{POR} is the correction factor for Porosity. (refer Fig. 8)

K_{DRI} is the correction factor for DRI, (refer Fig. 9)

K_S is the correction factor for jointing/fractures, (refer Fig. 10)

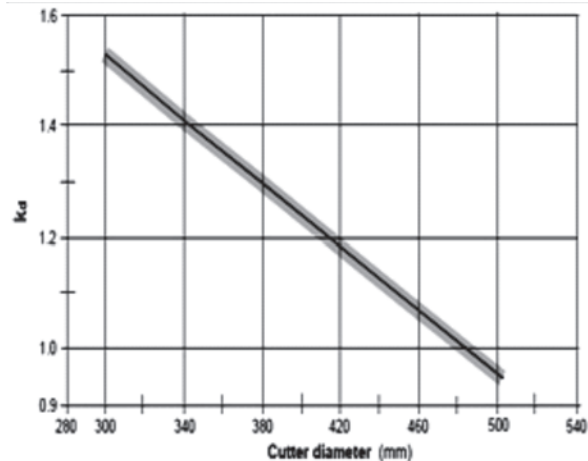


Fig. 6

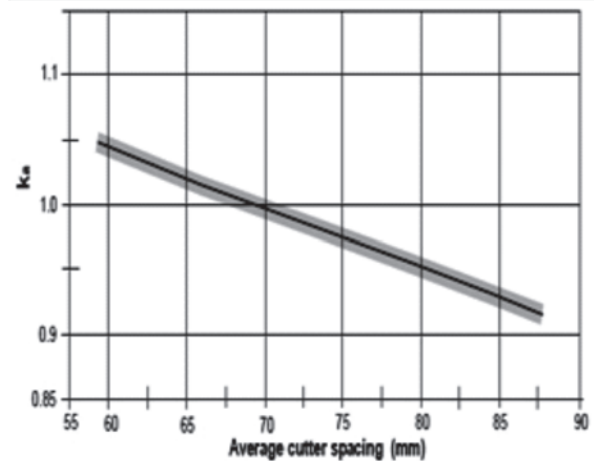


Fig. 7

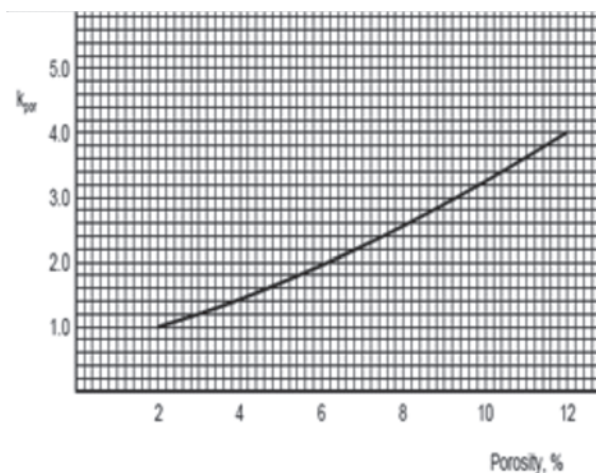


Fig. 8

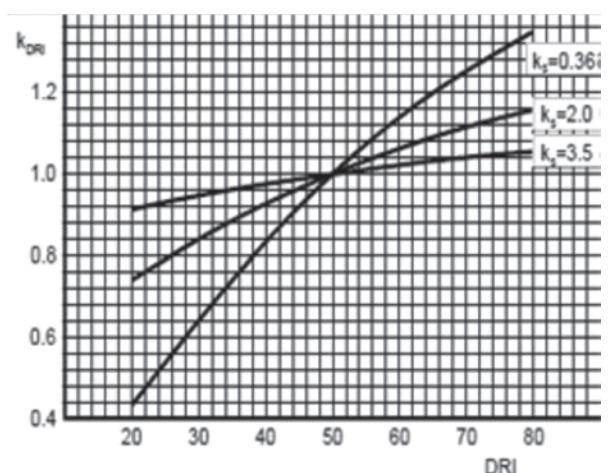


Fig. 9

M_1 and b values for obtained K_{EQ} values are obtained from Figure 11 and Figure 12.

The penetration rate is calculated using the relation (1) as follows:

$$I_o = (M_{EQ}/M_1)^b = (313/80)^{1.7} = 10.16 \text{ mm/rev}$$

The net advance rate (m/h) is found from relation (4):

$$I = (I_o) \times (\text{RPM}) \times 60/1000 = 10.16 \times 4 \times 60/1000 = 2.44 \text{ m/h} \quad \dots(4)$$

$$\text{Daily Advance (D}_A\text{)} = (I) \times (W) \times (U) = 2.44 \times 12 \times 0.4 = 11.7 \quad \dots(5)$$

Where,

I_o is the instantaneous penetration rate (mm/rev).

RPM is rotation per minute.

W is working hours available per day (two shifts with 6 hours at face)

U is the utilization factor (%)

D_A is advance per day (m/day)

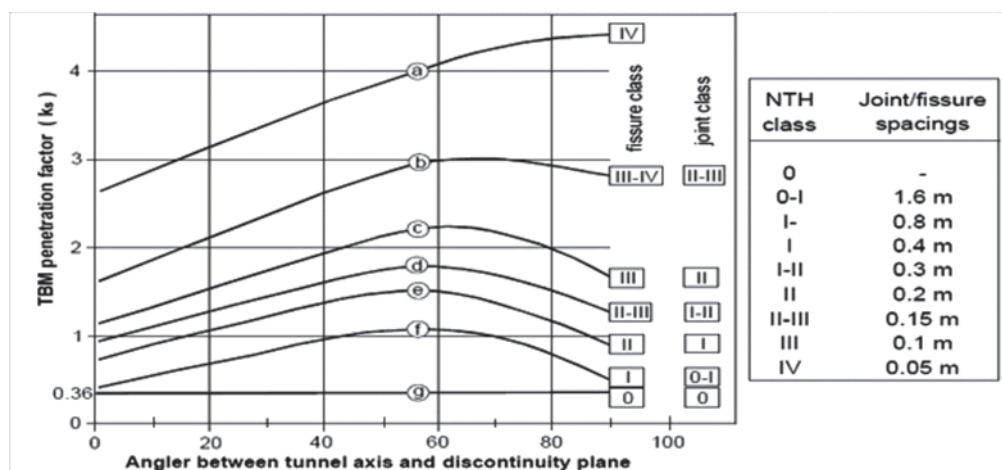


Fig. 10

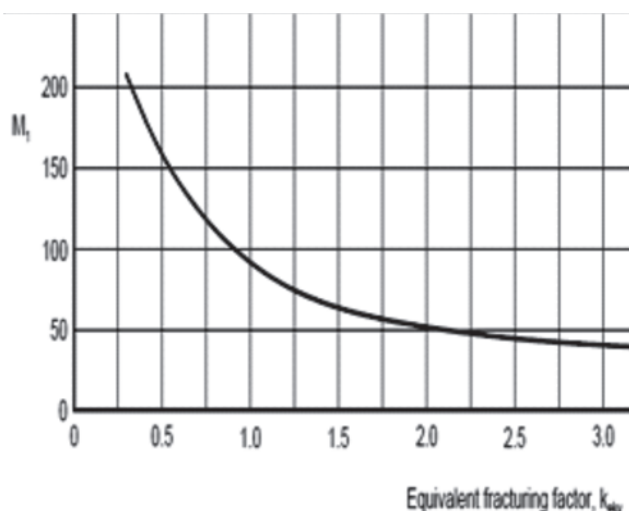


Fig. 11

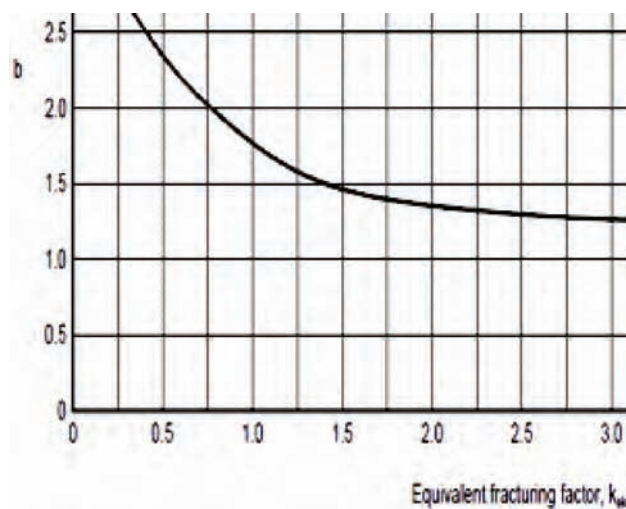


Fig. 12

RMI-NTH Model

5. CONCLUSION

Feasibility of a TBM is very much based on the ability of TBM and its other back up equipment to perform efficiently under the averages obtained from the different lab and field investigations defining the favorable or the adverse geological condition. Previous tunnelling experience in India has proved that geology has often played a decisive role in deciding the success or failure of the project. TBMs to be used for tunnelling in hard rock terrain have to be designed and selected to be able to sustain mixed faced conditions (MFC) also. Thus, it is very important that planning, design and preparation of contract documents take the responsibility of MFC into consideration apart from the variations in rock properties. All the TBM drivages must take into cognizance the variations in geology and this can be best achieved through a careful sample selection followed by a comprehensive testing programme.

This data will be immensely useful in designing the TBM systems may it be using NTH or CSM or Q_{TBM} or RMI-NTH methods. Specialised tests, namely, DRI, CAI and Brittleness were found to relate reasonably well with the penetration rate achieved. Thin section analysis and identification of microstructure has also helped understand the reasons for poor boreability and higher cutter rate consumption. Physico-mechanical properties help in designing the overall system. Test data generated for Tapovan-Vishnugad Hydel Project by ISM has been utilized to estimate the basic penetration rate with RMI-NTH model. This can be used, rock suit-wise, for arriving at the daily advance (assuming suitable utilization of machine). Considering the established utility of lab tests, it is needless to re-emphasize the need for extensive laboratory studies during planning stage of tunnelling with TBM. However, the predicted penetration rates in different rock suits need to be correlated with

actual penetration achieved in the field for the better appreciation of the entire process and develop useful guidelines in Indian scenario as TBM tunnelling is going to catch up further.

Acknowledgement – Authors thankfully acknowledge all the concerned officers and management of NTPC LTd. and NHPC Ltd. for assigning rock mechanics investigations pertaining to various Hydel Projects of the country and also for their continuous involvement through various executive development programmes on drilling, blasting and tunnelling. Support of ISM in providing needful support and facilities is also thankfully acknowledged. Special thanks to Mr. Jerrin Jose, PG scholar for helping to prepare the paper and Shri B.Munshi, STA to support the laboratory studies. The views expressed are of the authors and not necessarily of the organizations they represent.

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INFLUENCE OF ANISOTROPIC STRESS CONDITIONS ON DESIGN OF DEVELOPMENT WORKINGS IN BORD AND PILLAR MINING

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ABSTRACT

The knowledge of in-situ stress plays a vital role in design of any underground structure in rock. In mining context, the knowledge of in-situ stress becomes necessary at many stages of mine planning, viz. while deciding about the appropriate layout, designing the ground support and establishing a proper and efficient extraction sequence etc. In today's numerical analysis based problem solving approach, the state of subsurface stress or in-situ stress forms the basic input parameter for analysis of any rock mechanic problem. This paper discusses the directional role of high horizontal stress in Tandsi mine, of Western Coal Fields (WCL). An approach based on wedge analysis and stress analysis of the layout for bord and pillar mining is discussed in this paper. This helps in understanding the design requirements for proper layout plan.

1. INTRODUCTION

The distribution and magnitude of in-situ stresses affect the geometry, shape, dimensions, excavation sequence and orientation of underground excavations (Anireddy and Ghose 1994). The main goals when designing underground openings in rock / coal (where stresses are likely to be a problem) are to minimize stress concentrations, create a compressive stress field as evenly as possible (the harmonic hole concept) in the excavation walls and avoid tensile regions (Hoek and Brown 1980). This can be done by changing the shape and geometry of the openings as well as their orientation with respect to the known principal in-situ stress. The knowledge of in-situ stress direction plays a pivotal role in deciding the orientation and pillaring plan in coal mines (Doliner 2001, Doliner et al. 2001, Bigby et. al. 1992). Once the optimal orientation of the panel is decided, the size of the slices in bord & pillar mining can be optimized in order to prevent possible loss of coal in the goaf. Strata control problem associated with Tandsi mine, Western Coal Fields, India is discussed in this paper.

2. SALIENT FEATURES OF THE MINE

Tandsi Mine lies in the in Chindwara district of Madhya Pradesh. Damua the nearest town is connected with Dungaria (headquarter of Kanhan area, WCL) and Parasias (headquarter of Pench area, WCL) by a metaled road (Figure 1). The detailed exploration in Tandsi block has proved the existence of three coal seams designated from top to bottom as seam – III, II and I. Seam III is persistent in nature as well as attained workable thickness in the entire mine area. This is the main potential seam. Seam

II has not attained workable thickness of 1.2m and above anywhere in the explored area, while seam I has attained workable thickness of 1.2 m and above in some part of the area explored. The present mining is concentrated at 3.5 m thick seam III which is at a depth of 230 m below the ground level. The strike of the coal seam in major part of the area is generally EW with localized swings and an average gradient of 1 in 15. The immediate roof (3.5 m thick) of seam III is made of fine to medium grained grey white, moderately hard sandstone with occasional bands of shale and carbonaceous shale streaks at places. The floor consists of sandstone frequently inter bedded with shale and carbonaceous shale. There are no overlying or underlying workable seams in the mine.



Fig. 1 : Location Map of the Tandsi Mine, Madhya Pradesh, India

The access to the mine is through four inclines driven up to the coal seam. The development of the mine was carried out by driving mutually perpendicular headings at a spacing of 45m center to center, thereby creating an array of pillars of size 45 m x 45 m center to center (Figure 2). The set of headings (almost EW direction) driven along the strike of the coal seam are called level galleries and the other set of headings perpendicular to the level galleries are the dip-rise galleries or simply dip galleries. The headings had a rectangular cross section of 3.6 m width and 3.0 m height. The excavation was carried out using drilling and blasting using Class V permitted explosives and delay detonators to minimize blast damage to excavations.

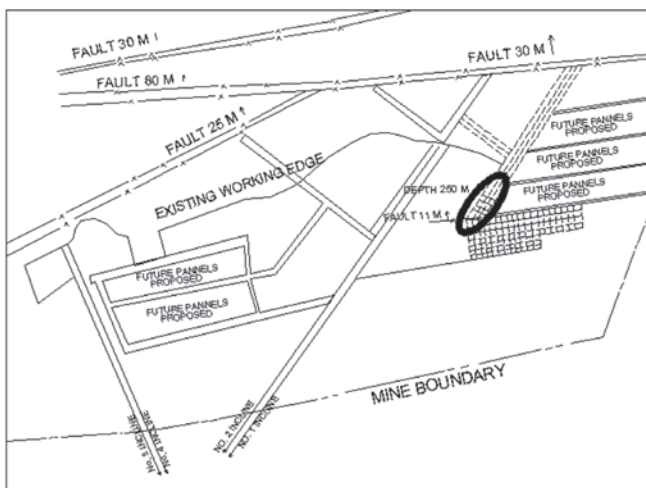


Fig. 2 : Key plan showing the roof fall problems encountered at Tandsi mine

3. MINING PROBLEM UNDER INVESTIGATION

In order to achieve trouble free mining operation and sufficient ventilation to the working faces it is desirable that all the galleries be stable enough to provide access to the man and material as well as the passage of fresh air to the working faces. During development, roof falls were encountered in dip galleries close to 12th, 14th and 16th levels (Figure 2), ellipse portion shows location of the roof falls). In some instances the roof falls were extended up to the Rider Seam. Though there was no change in the geometry of the mining and the physical properties of the rock and coal, the pattern of roof fall were not continuous and restricted in to certain areas. The roof conditions deteriorated upon development even after immediate supporting, due to shear breaks in the roof abutments (Figure 3). The same set of level galleries/dip-rises having similar rock type, strike of the bed and joint pattern did not have continuous roof problems. The role of re-orientation of the in-situ stress due to influence of discontinuities was

suspected in case of Tandsi mine. The other probable factors causing roof failure can be:

- (i) The effectiveness of the roof bolting system. Both the level and dip galleries were supported systematically and no delay in supporting the faces were reported. The anchorage tests of the bolts indicated load bearing capacity of 10 T.
- (ii) Method of blasting. No blast damage was reported in the mine, as Class V permitted explosive and delay detonators were used for blasting. Over breaks were also not reported.
- (iii) Structural instability due to wedge formation in roof of the galleries. A detailed analysis of the wedge formation and its stability is discussed in section 4.0 of this paper; this also negates the cause of roof failure due to structural instability.



Fig. 3 : Nature of roof instability in 14th Level at Tandsi Mine.

The factors such as the effectiveness of roof bolting system, method of blasting and structural instability negated the cause of roof failures. Detailed numerical analysis of the stress induced failure (Sengupta et al. 2011) proved the dominant role of the influence of the direction of the in-situ stress and possible influence of the stress perturbation due to faults. The present paper investigates in detail the role of structural instability due to formation of wedges in the roof and the directional role of in-situ stress through numerical modeling for orientation of safer and trouble free galleries.

Prior to the stress measurement at Tandsi Mine, the management of the mines had made many trial and error combinations by reducing the width of the galleries to 3.6 m from an initial width of 4.5 m. The details of different combinations for support system resorted by the mine management is given in Table 1, however none of the methods were found effective.

Table 1 : Summary of the different system of support, tried by the mine management, for development galleries at Tandsi mine

Parameter	Option 1	Option 2	Option 3	Option 4
Roof span (m)	4.5	3.6	3.6	3.6
System of support	roof bolt	roof bolt	roof stitching	roof bolt with W-strap
Length of bolt (m)	1.5	1.5	1.8 and 1.5 m long eye bolts	1.8
No of bolts in a row	3	3	2	4
Spacing between rows	1	1	1	0.9
Distance from pillar side and angle of the bolt	0.75	0.3	0.3	0.3
Performance of Support	Massive roof falls at number of places	Roof falls at number of places	Roof falls in level and dip galleries	Frequent roof falls reduced

Table 1 : (Contd.)

Parameter	Option 5	Option 6	Option 7
Roof span (m)	3.6	3.6	3.6
System of support	roof bolt with W-strap	resin bolting with w strap	resin bolting staggered pattern
Length of bolt (m)	1.8	2.1	2.1
No of bolts in a row	4	5	4/5
Spacing between rows	0.5	0.6	0.6
Distance from pillar side and angle of the bolt	0.3	0.3	0.2
Performance of support	Roof falls at number of places	Roof falls at number of places	Roof falls at number of places
Note: Pillars have no sign of loading however cracks were observed in the roof of the gallery, in all the options at some places			

4. WEDGE ANALYSIS OF THE DISCONTINUITIES ENCOUNTERED AT TANDSI MINE

RMR report of the Tandsi mine, prepared by WCL Nagpur, provided by the mine management, reveals two sets of predominant vertical joints observed in the sandstone. One of the joint sets trending N-S and the other N150°. The joint along the seam is another obvious joint set, which has been considered for the wedge analysis.

The wedge analysis of Tandsi mine was carried out using the Software 'Unwedge' Supplied by Rocscience Inc. Canada. The software Unwedge carries out a series of calculations based on the input provided by the user in terms of the geometry of the opening, the joint set information, the joint property and the support information. The calculation steps include:

1. Determination of wedge geometry using block theory (Goodman and Shi, 1985)
2. Determination of the individual forces acting on a wedge and then calculation of the resultant active and passive force vectors for the wedge.
3. Determination of the sliding direction of the wedge.

4. Determination of the normal forces on each wedge plane.
5. Computation of the joint shear strength, and tensile strength (if applicable)
6. Calculation of factor of safety against sliding of the block.

Wedges are formed by the intersection of 3 – joint planes and excavation. The wedges so formed are tetrahedral in shape (in general the three joint planes forms the three sides of the tetrahedron and the fourth side is formed by the excavation boundary). In an Unwedge analysis there are fair chances of formation of prismatic wedges, this occurs if two of the joint planes strike in the same direction resulting in a prismatic shape rather than the tetrahedral shape of the wedge. The geometrical properties of each wedge are described by its volume, wedge face area and the normal vectors for each wedge plane.

The forces acting on the wedge are categorized into two types, viz. the active and passive forces. These forces are utilized in the calculation of the factor of safety of the wedges. All driving forces are treated as active forces

and all resistive forces are treated as passive forces. The active force vector is given by equation (1):

$$\vec{F}_A = \vec{F}_W + \vec{F}_C + \vec{F}_X + \vec{F}_U + \vec{F}_E \quad \dots(1)$$

Where, \vec{F}_A = resultant active force, \vec{F}_W = vector representing wedge weight, \vec{F}_C = vector representing the weight of shotcrete on the wedge, \vec{F}_X = active pressure (Support) force vector, \vec{F}_U = water force vector and \vec{F}_E = seismic force vector. The passive force vector is given by equation (2):

$$\vec{F}_P = \vec{F}_H + \vec{F}_Y + \vec{F}_B \quad \dots(2)$$

Where, \vec{F}_P = resultant passive force vector, \vec{F}_H = shotcrete shear resistance force vector, \vec{F}_Y = passive support pressure force vector and \vec{F}_B = resultant bolt force vector.

Once the active forces are computed, this is utilized for determination of the direction of the sliding of wedge. It is worth noting that the passive forces do not influence the sliding direction. For any tetrahedron, there can be 7 – possible directions of sliding ($\vec{s}_0, \vec{s}_1, \vec{s}_2, \vec{s}_3, \vec{s}_{12}, \vec{s}_{23}, \vec{s}_{31}$). The vector represents the mode of falling or lifting of the wedge. The \vec{s}_1, \vec{s}_2 and \vec{s}_3 vectors represent the mode of sliding on a single plane. The $\vec{s}_{12}, \vec{s}_{23}$ and \vec{s}_{31} vectors represent the mode of sliding of the wedge along the line of intersection of two joint planes. The equations for the sliding direction vectors are given by equations (3), (4) and (5).

$$\vec{s}_0 = \hat{a} = \frac{\vec{F}_A}{|\vec{F}_A|} \quad \dots(3)$$

$$\vec{s}_i = \frac{(\hat{n}_i \times \vec{F}_A) \times \hat{n}_i}{|(\hat{n}_i \times \vec{F}_A) \times \hat{n}_i|} \quad \dots(4)$$

$$\vec{s}_{ij} = \frac{\hat{n}_i \times \hat{n}_j}{|\hat{n}_i \times \hat{n}_j|} \text{sign}((\hat{n}_i \times \hat{n}_j) \cdot \vec{F}_A) \quad \dots(5)$$

Where, \vec{s}_0 = falling or lifting direction of wedge, \hat{a} = unit direction of active force, \vec{F}_A = resultant active force, = sliding direction on joint 'i', \hat{n}_i = normal to joint face 'i' directed into wedge, \hat{n}_j = normal to joint face 'j' directed into wedge and \vec{s}_{ij} = sliding direction on joint 'i' and 'j' (intersection of joints).

After the evaluation of the sliding direction, the evaluation of normal force on each of the three joint planes of the tetrahedron is affected. The equations (6), (7) and (8) describe the normal forces on the planes of the tetrahedron.

For falling or lifting wedge $N_i = 0, N_j = 0, N_k = 0 \quad \dots(6)$

For sliding on a single joint 'i' $N_i = -F_A, N_j = 0, N_k = 0 \quad \dots(7)$

For sliding along joint 'i' and 'j'

$$\left. \begin{aligned} N_i &= -\frac{(\vec{F}_A \times \hat{n}_j) \cdot (\hat{n}_i \times \hat{n}_j)}{(\hat{n}_i \times \hat{n}_j) \cdot (\hat{n}_i \times \hat{n}_j)} \\ N_j &= -\frac{(\vec{F}_A \times \hat{n}_i) \cdot (\hat{n}_j \times \hat{n}_i)}{(\hat{n}_j \times \hat{n}_i) \cdot (\hat{n}_j \times \hat{n}_i)} \\ N_k &= 0 \end{aligned} \right\} \quad \dots(8)$$

Now, for the computation of the resisting force on the wedge, the normal force acting on each joint plane is evaluated. The normal stress is computed based on the active and passive normal force computed on the joint plane and is given by equation (9).

$$\sigma_{ni} = \frac{N_i}{a_i} \quad \dots(9)$$

Where, σ_{ni} is the i^{th} joint plane, N_i is the normal force on the i^{th} joint and a_i is the area of the i^{th} joint. The resisting stress due to the shear strength of the joint is represented by the Mohr-coulomb failure criteria given by

$$\tau_i = c_i + \sigma_{ni} \tan \phi_i \quad \dots(10)$$

Eventually the resisting force due to shear strength of the joint is given by

$$F_{ji} = \tau_i a_i \cos \theta_i \quad \dots(11)$$

Where, F_{ji} = the magnitude of the resisting force due to shear strength of the joint 'i', τ_i = the shear strength of the joint 'i', a_i = the area of the joint 'i', c_i = the cohesion of the joint plane ϕ_i = the angle of internal friction of the joint strength and the angle between the sliding direction and the i^{th} joint.

The resisting force due to the tensile strength of the joint is taken as zero for the analysis in this paper.

Finally the factor of safety for the three cases viz., (i) the falling factor of safety - F_f (ii) unsupported factor of safety - F_u and (iii) the supported factor of safety - F_s is calculated. The maximum amongst the three is reported as the factor of safety of the wedge.

As per the development carried out at Tandsi mine, four directions of galleries (Table 2) will be sufficient to represent the drivage of the mine. Table 3 lists the details of the joint sets present in the roof.

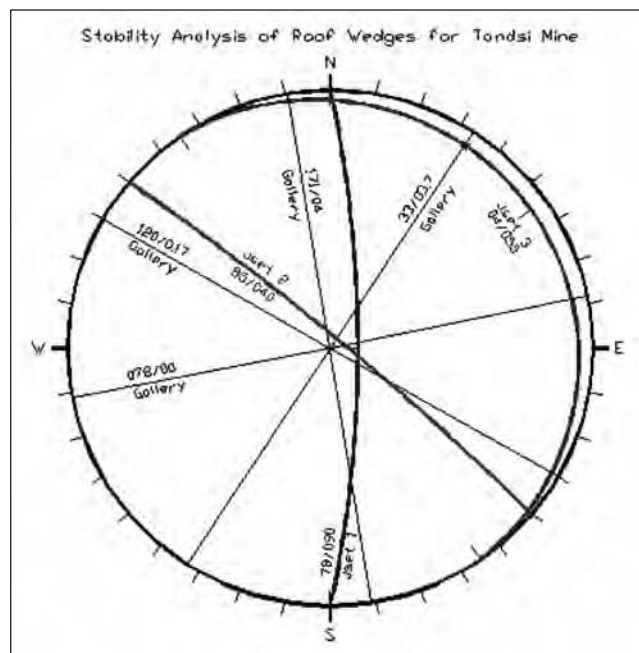
Table 2 : Direction of galleries at Tandsi mine.

Sl. No.	Location	Gallery	Trend	Plunge
1	26D / 9L	Level	078	00
2		Dip / Rise	171	04
3	10D / 14L	Level	120	01.7
4		Dip / Rise	033	03.7

Table 3 : List of predominant joint sets in the roof at Tandsi mine.

Joint Set No.	Strike of joint set	Dip of the joint set	Dip Direction
1	N – S	78	090
2	N 150E	85	040
3	N145E	04	055

The size or the weight of the wedge formed if any in the roof will depend on the size of the gallery. Only roof wedge formed in the upper part of the gallery is considered from the output provided by Unwedge software, as the joint sets considered here is for roof strata only, not in the coal seam or the floor rock. With the worst possible scenario, considering no support, the wedge analysis for different size of the gallery was carried out. This is tabulated in Table 4. The input to the Unwedge software is from Tables 2 and 3 which lists the direction of the galleries and the three set of joints prevalent in the roof of the mine. In the absence of the proper joint property measurement, the most representative values of joint shear parameters for coal measure rocks as suggested by Barton (1974) have been used. The cohesion is taken as 0.012 MPa and the angle of internal friction is considered as 16 degrees for all the joint sets. An output from the

**Fig. 4** : Stereographic plot of joint vis-a-vis the gallery directions

Unwedge Software showing the stereographic plot of the joint sets vis-a-vis the gallery directions is given in Figure 4. The results of Unwedge analysis is summarized in Table 4. Representative output from the Unwedge Software is given in Fig. 5.

Table 4 : Summary of roof wedge analysis for Tandsi Mine

Gallery	Trend / Plunge	FOS and roof wedge information in 3.6m wide and 3.0 m high gallery without support	FOS and roof wedge information in 4.2 m wide and 3.0 m high gallery without support	FOS and roof wedge information in 4.5m wide and 3.0 m high gallery without support
26D/9L Level	078/00	FOS=0.682 Weight = 0.071 ton Slides along Jset1 in the direction 090/78	FOS=0.593 Weight = 0.113 ton Slides along Jset1 in the direction 090/78	FOS=0.558, Weight = 0.139 ton. Slides along Jset 1 in the direction 090/78.
26D/9L Dip Rise	171/04	FOS=1.12, Weight = 0.492 ton. Slides along Jset 2 in the direction 040/85	FOS=0.963, Weight = 0.782 ton. Slides along Jset 2 in direction 040/85.	FOS = 0.901, Weight = 0.962 ton. Slides along Jset 2 in the direction 040/85.
10D/14L Level	120/01.7	FOS=0.626, Weight = 7.922 ton wedge in roof. slides along Jset 2 in the direction 040/85	FOS=0.502, Weight = 12.269 ton wedge slides along Jset 2in the direction 040/85.	FOS = 0.456. Weight = 14.948 ton wedge. slides along Jset 2 in the direction 040/85.
10D/14L Dip Rise	033/03.7	No wedge formed in the roof.	No wedge formed in the roof.	No wedge formed in the roof.

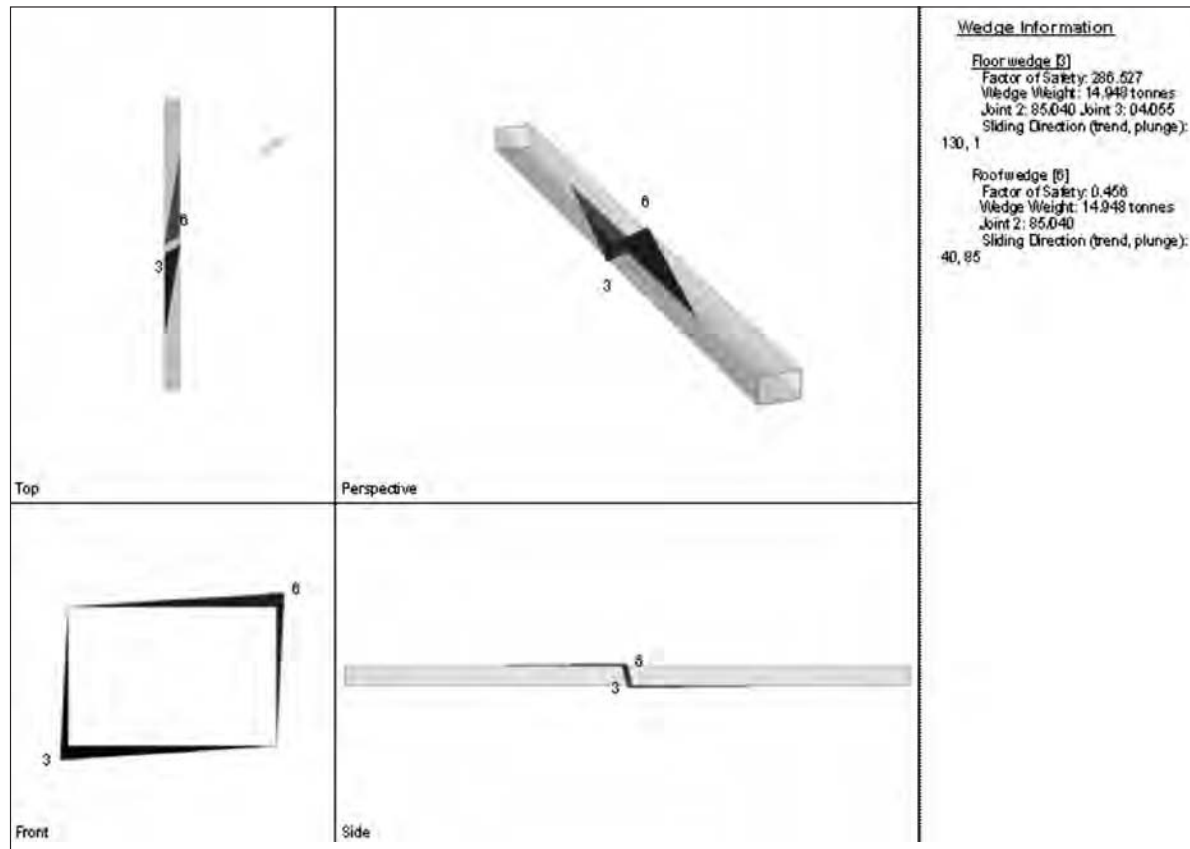


Fig. 5 : View of the wedges formed, with gallery orientation 120/01.7, Output from Unwedge software.

As observed from the stereographic plot of the joints vis-a vis the gallery directions as shown in Fig. 4 and summary of the results of Unwedge analysis in Table 4, the following observations are made:

1. For the gallery 078/00, wedge is formed in the roof and tends to drive the wedge along Joint set 1. The wedge weight increases as the width of the gallery is increases. The factor of safety for 4.5 m gallery is 0.558 without any support or shotcrete. The wedge weight being 0.139 ton and extends barely high enough into the roof, this means a minimal support of less than 1 ton capacity can support the roof effectively.
2. For the gallery 171/04, wedge is formed in the roof and tends to drive the wedge along Joint set 2. The wedge weight increases as the width of the gallery is increases. The factor of safety for 4.5 m gallery is 0.901 without any support or shotcrete. The wedge weight being 0.962 ton and extends barely high enough into the roof, this means a minimal support of less than 1.5 ton capacity can support the roof effectively.
3. For the gallery 120/01.7, wedge is formed in the roof and tends to drive the wedge along Joint set 2. The wedge weight increases as the width of the gallery

is increases. The factor of safety for 4.5 m gallery is 0.456 without any support or shotcrete. The wedge weight being 14.98 ton and extends barely high enough into the roof, this means a minimal support of three bolts of length 0.5 m with capacity 6 ton each can support the roof effectively to a factor of safety 2.0.

From the results of the Table 4 and the observations of the Unwedge analysis, it is quite evident that the roof falls as reported in Tandsi Mine is not because of any structural instability (Wedge failure), rather it indicates towards the role of high horizontal stresses that may be creating trouble in the roof strata.

5. Investigation of Stress Redistribution due to Mining Geometry

Investigation conducted in Australian coal mines (Gale and Fabjanczyk, 1991) has established a relation between roof failure in the roadways and the angle between the roadway axis and the maximum horizontal stress direction. Actual measurement of stress in vicinity of the fault zone proved the rotation of the stress direction along one of the galleries (Sengupta et.al 2011), while the regional stress direction away from the fault zone was at 45 degrees to galleries. In a typical bord and pillar mining method the dip drives and level galleries are

driven perpendicular to each other. Now in a particular set of direction of maximum horizontal stress one of these may be oriented unfavorably with the orientation of the maximum horizontal stress. A detailed investigation is carried out by numerical modeling to establish the most favorable direction of the dip drives/level galleries vis a vis direction of maximum principal horizontal stress from the stability point of view. For the study of redistribution of stresses due to change in mining geometry three cases were considered.

Case 1: Orientation of Max. Horizontal Principal Stress (σ_H) is perpendicular to orientation of level gallery.

Case 2: Orientation of Max. Horizontal Principal Stress (σ_H) is parallel to orientation of level gallery.

Case 3: Orientation of Max. Horizontal Principal Stress (σ_H) is 45° to orientation of level gallery.

The objective of the study is to estimate effect of the above three conditions on the stability of roof so that proper measure can be taken to reduce the roof stability problem by change in geometry of the workings and also to estimate the support requirement.

5.1 Model Setup for Evaluating Re-orientation of Development Working

To investigate the effect of in-situ stress direction on working of a developed bord and pillar panel, a panel of 3×3 pillars was made in EXAMINE3D program. Pillar size of 45m center to center and the gallery size of 4.5m x 3m were selected. Development excavations were made by use of polylines and node lines. Between the two node lines the skin of the excavation was extruded. The skin of excavation was discretized using the default discretization scheme of the program with a mesh density factor of unity. The crossing of excavation was made by deleting the required elements from the crossing points; a node line was drawn along the deleted portion of the excavation, this node line was extruded up to the next crossing point to form a leakage proof excavation Fig. 6.

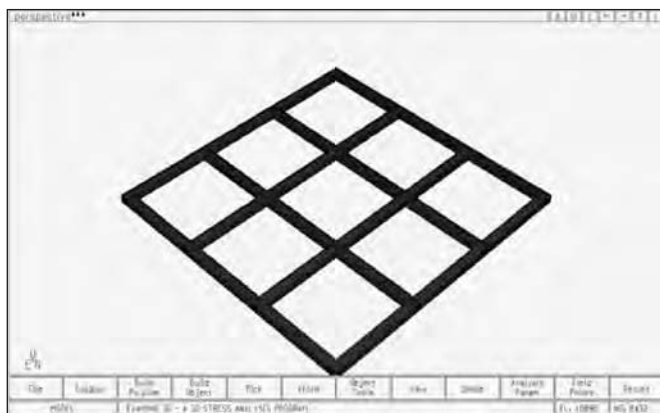


Fig. 6 : Discretized model for a 3×3 pillar development panel in Examine 3D

5.2 Initialization of In-Situ stress in Examine 3D

Examine 3D has an option of using the gravity as well as the in – situ stress data. The in – situ stress values can be fed in the form of principal stresses with their respective dip and dip direction. The measured value of the regional stress for Tandsi mine (Sengupta et al. 2004) was utilized, which is tabulated in the form of input required by Examine3D.

Table 5 : In-situ stress values of Tandsi Mine, used in Examine 3D, when the major principal stress is along level galleries

	Major Principal Stress (σ_H)	Intermediate Principal Stress (σ_V)	Minor Principal Stress (σ_h)
Magnitude (MPa)	9	4.5	5
Direction (degrees)	90	0	0
Dip (degrees)	0	0	90

To evaluate the second option when the major principal stress is perpendicular to the level gallery, the stress directions of σ_H and σ_h as given in Table 5 above is interchanged.

For evaluating the third option of the case when the major principal stress is at an angle of 45° from the level gallery and still horizontal. The Stress directions were changed in the input as given in Table 6.

Table 6: In-situ stress values of Tandsi Mine, used in Examine 3D, when the major principal stress is at an angle of from the level galleries.

	Major Principal Stress (σ_H)	Intermediate Principal Stress (σ_V)	Minor Principal Stress (σ_h)
Magnitude (MPa)	9	4.5	5
Direction (degrees)	135	45	0
Dip (degrees)	0	0	90

Thus overall the stress orientation in the three cases is as follows:

Case 1 : the major principal stress acts along east – west direction. The galleries are driven north – south and east – west.

Case 2 : the major principal stress acts along north – south direction. The galleries are driven north – south and east – west.

Case 3 : the major principal stress acts along Northeast – Southwest direction. The galleries are driven north – south and east – west.

5.3 Rock Mass Property and Failure Criteria for Evaluating the Factor of Safety

The rock mass elastic modulus was taken as 5.0 GPa and Poisson's ratio of 0.25 was utilized in the model. For Indian coal measure rocks, the Sheorey's Failure criterion has been found suitable by researchers in India (Murali Mohan 2001). This criterion uses the 1976 version of RMR of Bieniawski for reducing the laboratory strength parameters to give the corresponding rock mass values. The basic CMRI –ISM RMR is directly used here instead of Bieniawski's RMR, since this procedure has been found to be acceptable after application in 18 - coal mine cases (Kushwaha et.al 2010). Sheorey's criterion for rock masses is defined as:

$$\sigma_1 = \sigma_{cm} \left(1 + \frac{\sigma_3}{\sigma_{tm}} \right)^{b_m} \quad \dots(12)$$

The subscript m refers to rock - mass, where σ_1 is the triaxial strength of rock mass (MPa), σ_3 is the minor principal stress or the confining stress (MPa), b_m is the exponent of the failure criterion that controls the curvature of the non-linear Sheorey's failure criterion σ_{cm} and σ_{tm} and σ_{tm} is the compressive strength and tensile strength of the rock mass respectively, which is defined as :

$$\sigma_{cm} = \sigma_c \exp \left(\frac{RMR-100}{20} \right) \quad \dots(13)$$

$$\sigma_{tm} = \sigma_t \exp \left(\frac{RMR-100}{27} \right) \quad \dots(14)$$

$$b_m = b_{100}^{\frac{RMR}{100}}, b_m < 0.95 \quad \dots(15)$$

The symbols without the subscript m are the laboratory determined values for intact rock.

As the program Examine 3D has no facility for using different failure criteria other than the Mohr coulomb and the Hoek and Brown failure criterion; the Mohr Coulomb Equivalent (best fit) of Sheorey's failure criterion was used. The rock mass shear strength (or cohesion) τ_{sm} , the coefficient μ_{Om} and the angle of internal friction ϕ_{Om} are obtained from Sheorey's criterion as

$$\tau_{sm} = \sqrt{\sigma_{cm} \sigma_{tm} \frac{b_m b_m}{(1+b_m)(1+b_m)}} \quad \dots(16)$$

$$\mu_{Om} = \frac{\tau_{sm}^2 (1+b_m)^2 - \sigma_{tm}^2}{2\tau_{sm} \sigma_{tm} (1+b_m)} \quad \dots(17)$$

$$\phi_{Om} = \tan^{-1} \mu_{Om}$$

It is, however, found that the values of rock mass cohesion τ_{sm} and friction angle ϕ_{Om} has to be changed slightly to account for the fact that the Sheorey's Failure criterion

is nonlinear (Figure 7) in the form $\tau = \tau_{sm} \left(1 + \frac{\sigma}{\sigma_{tm}} \right)^{c_m}$, where $c_m = \mu_{Om}^{0.9} \frac{\sigma_{tm}}{\tau_{sm}}$, whereas the Mohr Coulomb criterion is linear. The value of τ_{sm} obtained from Sheorey's criterion was increased by 10% and that of ϕ_{Om} was reduced by 5° for use as Mohr Coulomb criterion. Considering large number of Indian case studies, Murali Mohan et al (2001) prescribed that the values determined by above mentioned method can be safely taken for modelling.

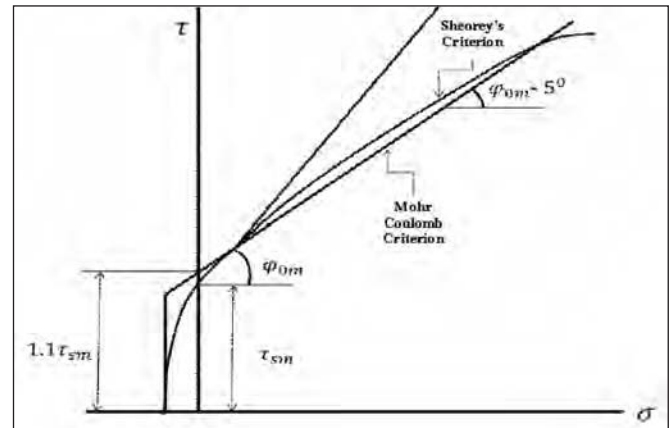


Fig. 7 : Schematic of using equivalent Mohr Coulomb Criterion of the Sheorey's Criterion.

Using the compressive strength of intact coal specimen as 42 MPa, tensile strength of 5 MPa and RMR of 56, the Mohr Coulomb equivalent cohesion is calculated as 1.33 MPa and angle of internal friction as 29.38 degrees.

5.4 Model Result of Re-orientation of Development Working

Plot of the factor of safety contours on the skin of the excavations during development shows major roof problems, when one of the stresses is parallel to either of the galleries (see the stress block in Figure 8); the area of the roof is completely filled with the FOS contours falling in the range of 0 to 0.7 (Figure 8) indicating directional failure. This situation is applicable to both the Case1 and Case 2.

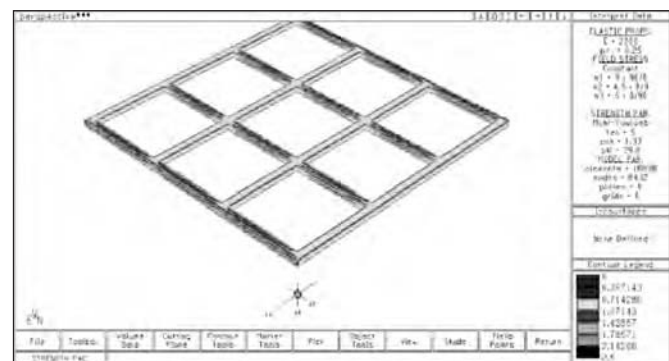


Fig. 8 : Plot of factor of safety contours on the skin of excavations during development, for the case, when one of the major horizontal stress is parallel to the east – west gallery.

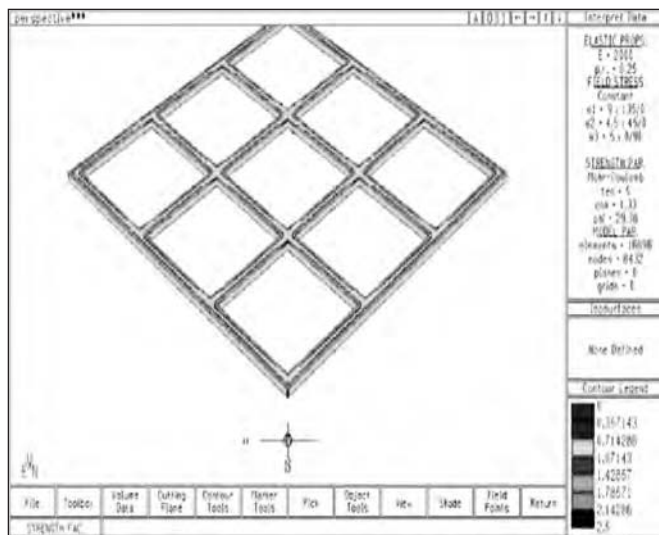


Fig. 9 : Plot of factor of safety (FOS) contours on the skin of excavations during development, for the case, when one of the major horizontal stress is at to one of the gallery. Shows reduced roof problems in both galleries.

But in the Case 3, when the major principal stress is oriented at to the working, the roof problem diminishes rapidly as seen in Fig. 9.

6. CONCLUSION

The wedge analysis of the Tandsi mine reveals that the existing joint sets have minimal effect on the instability of the roof. In fact the wedges extend into the roof up to 0.38 m and minimal roof bolting can provide sufficient stability of the roof. However, in actual the roof is found to be quite unstable even for rock bolts of length upto 1.8 m in length. There is no report of blasting damage or the delay in support installation. This calls for attention on other factor i.e. the stress related instability of the galleries at Tandsi mine. Detailed numerical modeling of the Tandsi mine reveals the following:

- Plot of factor of safety contours on the skin of excavations during development, for the case when one of the major horizontal stress components is parallel to the level gallery, the dip – rise gallery experience major roof problems (Figure 8).
- Plot of factor of safety, contours on the skin of excavations during development, for the case, when one of the major horizontal stress is at 45° to the level gallery. Shows reduced roof problems in both level as well as dip – rise galleries (Fig. 9).

Re-orientation of the development workings of the mine with respect to the direction of the in-situ stress can resolve the stress governed failure in the roof of the galleries.

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STRATA MONITORING STUDIES IN BLASTING GALLERY PANEL DURING DEPILLARING BASED ON FIELD INSTRUMENTATION

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A challenging task for mining professionals is to extract natural resources like coal from underground with utmost safety. The challenge becomes more when the thickness of coal seam is high. Blasting Gallery (BG) method of depillaring thick coal seam is one of the productive method with favourable economics, high production and productivity. In this method, stability of workings and easily cavability of goaf is very important for safely extraction of pillars, safety of men and machinery. In this paper, strata monitoring data of a blasting gallery panel is analyzed for the stability of pillars and workings in a Blasting Gallery panel during depillaring in specific geo-mining and working conditions of a underground mine in Southern part of India.

Keywords: *Underground coal mining, Thick seam mining, Blasting Gallery method, Strata monitoring studies.*

1. INTRODUCTION

In India, the gross reserves of coal are presently estimated at around 293.49 Billion tonnes (Bt) up to the maximum depth of 1200 m with proven reserves of 118.14 Bt, sufficient to last the next century at an annual rate of production of over 1180 Mt at present level of extraction (Anon, 2012). The demand of coal in the country is increasing year by year as energy sources from different industries. With the increasing demand of coal, more mechanized opencast mines are coming up. However, at present only 38% of Indian coal reserves is mineable by opencast mining within economic limit whereas the remaining 62% is to be exploited by underground mining (Singh et al., 2004). The share of underground coal production in the country has declined from 73% in 1974-75 to 10% in 2011-2012. For a healthy and balanced growth of coal mining industry in the coming decade, it is essential that underground production should increase at a more rapid rate. This is possible only by introducing extensive mechanization in underground mines and adopting new technologies.

About 50% of coal reserves in India are in seams thicker than 4.5m, which come under the category of thick seams, the exploitation of which is consistently posing challenges to the mining engineers. Extraction of thick seams by conventional hand section method is neither productive nor effective from the conservation point of view. The percentage of extraction by hand section mining in thick

seams is as low as 25-30%. Lot of good grade coal has been lost and million tonnes of coal are standing on pillars. Sand stowing for working of thick seams cannot be considered as an option because the cost is prohibitive. Sand has become an increasingly scarce commodity along with timber. At the same time, the coal industry was in search of an economic method to achieve higher percentage of extraction (70 – 85%) and needs a suitable technology to overcome the problems in the extraction of thick seams by conventional bord and pillar method.

Charbonnage de France (CdF) suggested Blasting Gallery (BG) method for extraction of virgin thick seams as well as developed pillars in thick seams. The first BG panel was started in the country at East Katras Colliery in Jharia Coalfield (BCCL) and Chora-10 Pit Colliery in Raniganj Coalfield (ECL) in the year 1987 in collaboration with France. Due to strata problems, the method was not successful at East Katras Colliery where overriding of the pillars occurred in one panel. Whereas at Chora-10 Pit Colliery, the method was partially successful giving encouraging results. However, the expected production and percentage of extraction could not be achieved in both the mines (Pandey et al., 1992). The Singareni Collieries Company Ltd. (SCCL) adopted this method in the year 1989 at GDK No. 10 Incline for extraction of coal in virgin area. The method was very successful resulting in 85% of extraction with high productivity (SCCL internal report, 2005). Realizing the rate of success, BG method of extraction is gearing up its future potentiality.

The soft nature of coal mass and presence of easily caveable overlying roof strata play a crucial role for the single working of a thick coal seam. However, both, the coal mass and the roof strata of Indian coalfields are, relatively, strong and massive. Here location of a prominent parting plane within the roof strata plays an important role in estimating the void between the caved wastes and overhanging roof inside the goaf. For these strata conditions, the value of limiting span of the overhang, generally, remains high, whose fall manifests dynamic loading over pillars facing goaf line. Due to increased height of the void to be filled, the problems associated with the dynamic loading need special attention for success of single lift working of a thick coal seam. So, BG panels need to be monitored with instruments for complete extraction of panels with safety without any strata problem by taking protective and precautionary measures beforehand. This paper discusses strata monitoring experiences of BG panel during depillaring in a given geo-mining and working conditions.

2. BLASTING GALLERY METHOD (BG)

In brief the method involves splitting along level of developed pillars in the bottom section, into two or three rectangular stooks (Fig. 1) and adequately supporting widened galleries by hydraulic props and roof bars at least two pillars ahead of the pillar under extraction. The stooks are extracted by drilling a ring of long holes upto the full seam thickness by Jumbo drills and blasting. The blasted coal from the goaf is loaded through the level galleries/splits by remote controlled load-haul-dumpers (LHD). LHDs discharge the coal into the armoured chain conveyors set within 100m from the extraction line for onward transport to a small bunker.

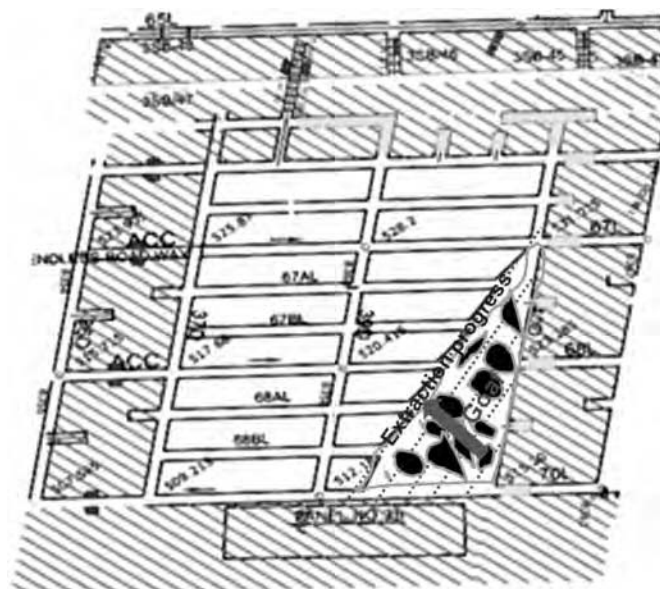


Fig. 1 : Typical layout of Blasting Gallery method in underground coal mine.

2.1 Preparatory Work

The galleries in the panel are widened to 4.8 m and heightened to 3 m for efficient manoeuvrability of LHDs and drill jumbos, and galleries upto two pillars of the line of extraction are supported by 40 tonne open circuit hydraulic props. The props are set at an interval of 0.7 m such that a clear space of 4.2 m was available for a free movement of the machines. The method of support of galleries and junctions in the panel is shown in Fig. 2. One chain conveyor in level is installed for coal transport to a bunker.

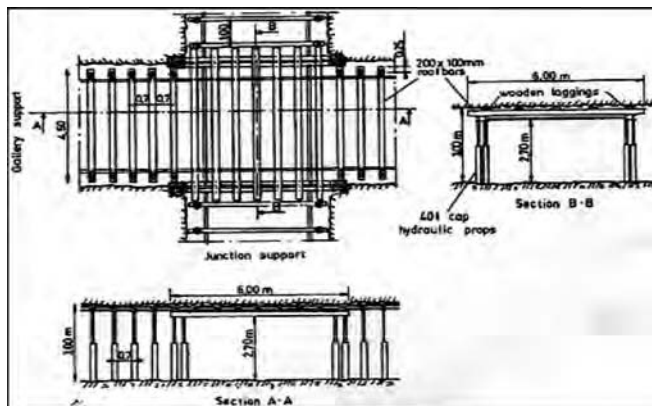


Fig. 2 : Junction and gallery support in bottom section at the working face (Gupta et al., 1990).

2.2 Method of Extraction

Initially, the pillars are divided by driving 4.8 m x 3 m level split galleries. The splitting of pillars is restricted to two pillars ahead of the line of extraction. A diagonal line of face is maintained at about 60°.

While retreating, the galleries are widened on both the sides by drilling long holes in a ring pattern upto the full thickness of the seam and blasting. Holes (42 mm) are drilled at an angle of 30° towards the goaf. The rings of holes are spaced at 1.4 m. Only one ring is drilled and blasted at a time. Drilling is done with the roof support but the supports are withdrawn just before the blasting. The pattern of drilling is shown in Fig. 3.

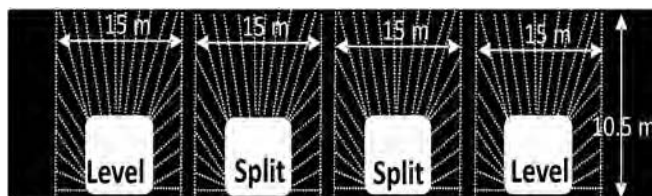


Fig. 3 : Ring hole blasting pattern and charge distribution

A special low strength explosive is used in long holes having the requirement of upto 2 kg per hole. A special non-incendive detonating cord is used in long holes. Hollow PVC tube spacers, 50 cm long, are used to separate the charge in the shot holes. A hollow PVC sleeve containing an explosive cartridge was inserted at

one metre inside the hole from the mouth which contained the end of the detonating fuse attached with an electric detonator as shown in Fig. 4. About 1 m long clay plug was provided upto the mouth of the hole in the conventional way. After charging, blasting is carried out. The blasted coal in the goaf was loaded by electro-hydraulic remote controlled LHDs. The remote control was pneumatically operated. The LHD travelled from goaf edge to the loading point and discharged on to armoured chain conveyor.

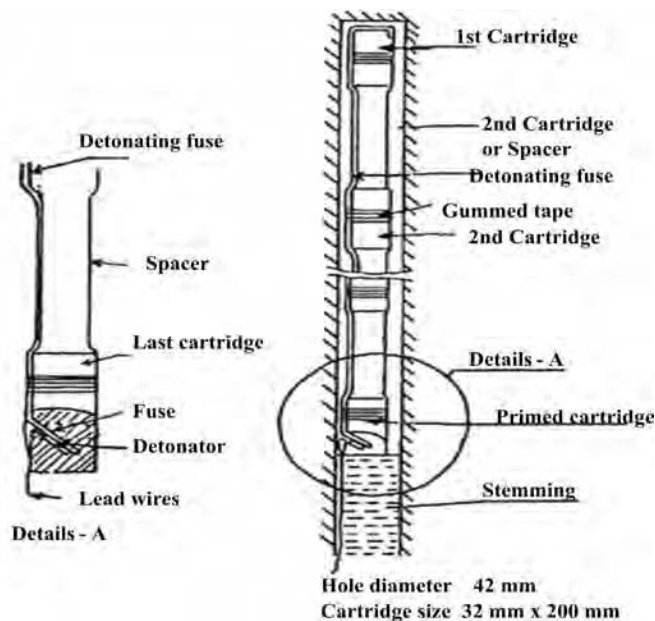


Fig. 4 : Charging details in ring holes (SCCL internal report, 2005).

2.3 Advantages with BG Method

The advantages of BG method include;

1. Extraction of 5-12 m thick seams in a single slice by caving.
2. Extraction of small size panels not suitable for longwall method.
3. Extraction of hard coals not suitable for ploughs and shearers.
4. Higher production and productivity.
5. Less capital intensive compared to longwall.
6. Less skilled man power is needed as compared to longwall.
7. In case of BG failure, the equipment can be used for heading drivages.
8. The workers/operators are always under the supported roof.

3. FIELD INVESTIGATIONS

The investigations were carried out in an underground coal mine with coal formations of Kamthi and Barakar series located in Southern India. Three seams are occurring in the mine viz., 3A Seam, 3 Seam and 4 Seam. The parting between No. 3A Seam and No.3 Seam is

40 m and between No.3 Seam and No.4 Seam is 4.5 m to 5.5 m. Blasting gallery technology is introduced and practised in 3 Seam. The seam no. 3 is dipping at about 1 in 5.2 lies at 321 to 348 m depth. The 10.97 m thick 3 seam is being worked in the bottom section to a height of about 3 m along the floor, leaving 1.5 m thick coal in the bottom, and area of the panel is 17369 m² consists of 6 pillars with 50 x 60 m size. It is overlain by a medium grained white sandstone by 23.16 m thick forms the main roof. The underlying No. 4 seam was unmined. The panel workings were observed free of water. Other overlying seams were found to be non-commercial (Fig. 5). The BG panel-3B, is selected for the present investigations.

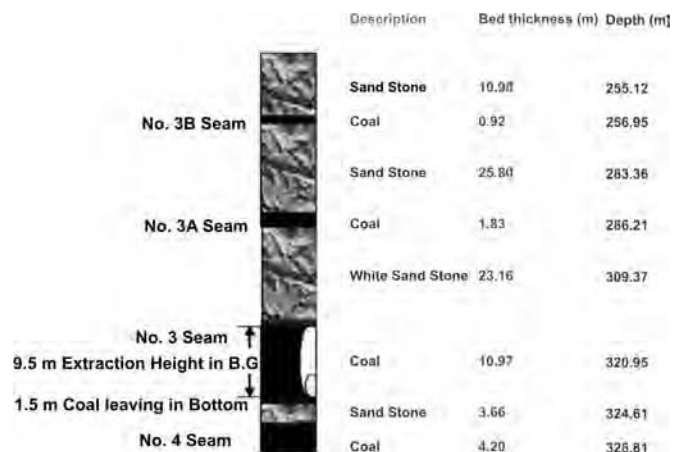


Fig. 5 : Borehole section No.441, GDK-10 Incline, SCCL.

An already-extracted panel was lying towards northern and western side of Panel-3B, whereas towards the south side and eastern, there was a virgin panel (Fig. 6). The immediate overlying strata were observed to be strong and massive with a caveability index of more than 2915 (NIRM, 1999). The presence of a difficult roof over the nearly 11 m high void in the goaf created difficult conditions for pillar mining the total thickness of the seam in a single lift. The increase in goaf height due to roof coal extraction by BG method was observed to be of considerable importance for stability of the pillars. There was a remarkable change in the width/height ratio of the pillars which faced the goaf of the adjacent mined pillars (Rajendra Singh, 2004).

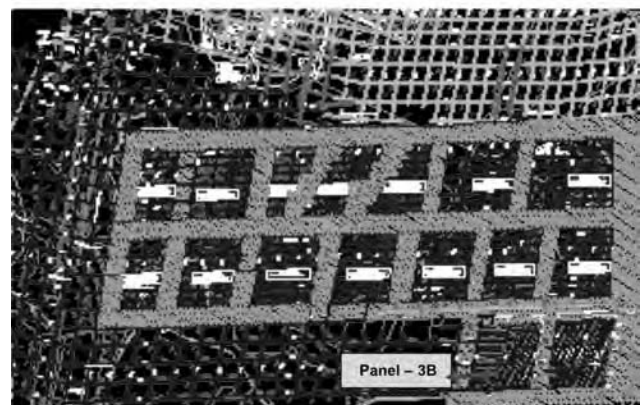


Fig. 6 : Plan of Pane-3B

Initially, 50 m x 60 m pillars were divided into three halves by driving 4.8 m x 3 m level split galleries. The size of stooks after splitting was 15.2 m x 50 m. The splitting of pillars was restricted to 2 pillars ahead of the line of extraction. A diagonal line of face was maintained at about 60°.

3.1 Safety Factor of the Pillars

Under normal pillar extraction condition, the local mine stiffness remains more or less constant while the reduction in pillar strength with the reduction in pillar size generates a situation conducive to violent failure. Here, increasing the extraction ratio by splitting/stoking of pillars ahead of the face may be dangerous to the working area. Laboratory scale specimens become elasto-plastic when width/height ratios approach 8 (Das 1986). In accordance with the field data available for the actual failure of a pillars (Sheorey 1993), the post failure modulus of a pillar with width/height ratio about 4 becomes positive and its behaviour changes from strain-softening to elasto-plastic. Fortunately, the BG does not involve the process of splitting/stoking ahead of the face, except for splitting and slicing the pillars being extracted. Under these conditions, the chance of the violent failure of a pillar becomes low and is limited to the pillar being extracted. The safety factor of the pillars of panel-3B remains nearly 2.33 for normal height (3 m) pillar extraction, while the same for full-height working of the seam by the BG method (11 m) with double splitting goes below one.

Table 1: Pillar size variation as per regulation 99 of Indian Coal Mining Regulations, 1957 (CMR 1957).

Depth cover (m)	Pillar size (center to center) for different gallery widths (m)			
	3.0 m	3.6 m	4.2 m	4.8 m
<60	12.0	15.0	18.0	19.5
60-90	13.5	16.5	19.5	21.0
90-150	16.5	19.5	22.5	25.5
150-240	22.5	25.5	30.5	34.5
240-360	28.5	34.5	39.5	45.0
>360	39.0	42.0	45.0	48.0

Pillars formed (Table 1) in accordance with the Coal Mining Regulations possess adequate safety factors and a high w/h ratio which sustain the various mining conditions resulting from pillar extraction at normal heights. However, there is an indirect increase in the height of pillars due to the winning of the roof coal by the BG method (Singh et al., 2007). The process of roof coal winning affects the stability of pillars designed for normal height workings developed in accordance with the Coal Mining Regulations.

3.2 Strata Monitoring

Field instrumentation was carried out in panel-3B to study stress distribution in the panel, load on hydraulic props in galleries, convergence in galleries, roof layers movement and stress change in the panel. Details of field instrumentation programme are given here (Fig. 7):

- *Stress measurements in BG workings.* Five vibrating wire stress cells, S_1 at 66BLN/39D, S_2 at 67LS/39D, S_3 at 67ALS/39D, S_4 at 68ALS/39D and S_5 at 68BLS/39D, were installed in the BG panel.
- *Load over O.C. props in galleries.* Vibrating wire load cells were installed on the O.C. hydraulic props, till 10 m ahead of working face in galleries. Recordings from load cells were obtained at every 10 m interval. Load cells were shifted to new stations after every 10 m of face retreat in the galleries.
- *Convergence in gate roads.* Roof to floor convergence was monitored at every 10 m interval in galleries using telescopic convergence indicators.
- *Immediate roof layers movement.* Three Tell-tale extensometers, T1 at 66L, T2 at 67L and T3 at 68L, were installed in the junctions of the BG panel.

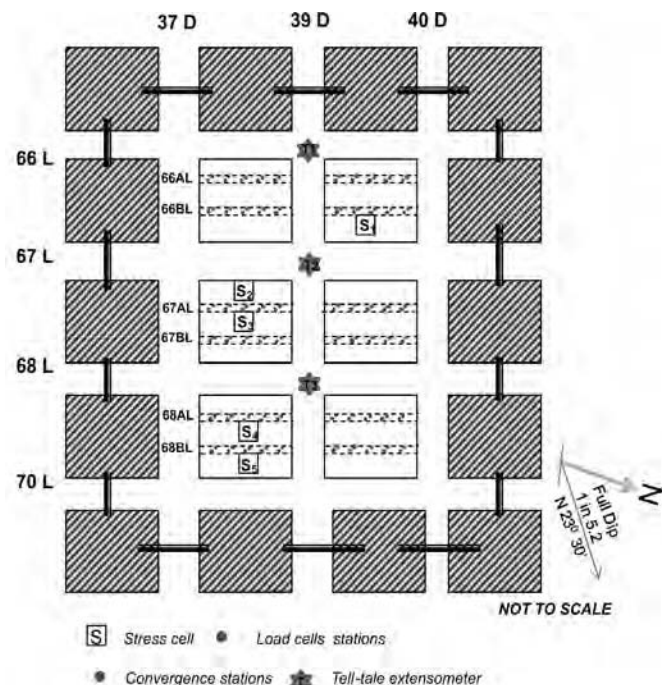


Fig. 7 : Location of different monitoring instruments.

4. RESULTS AND DISCUSSION

4.1 Stress Variation Over the Pillars

The measurements obtained from vibrating wire stress cells at 66BLN/39D (S_1), 67LS/39D (S_2), 67ALS/39D (S_3), 68ALS/39D (S_4) and 68BLS/39D (S_5) are presented

in Fig. 8 and 9. Variation of stress was found in all cells and its magnitude increased as the area of extraction increases and the face retreated closer to the station. It can be seen that the stress cell (S_1) recorded higher stress compared to other stress cells installed in the panel-3B. The reasons could be the large overhangs in goaf towards 66AL North, 66BL North and 67L North and nearer to the goaf edge distance compare to the other stress cells in the panel.

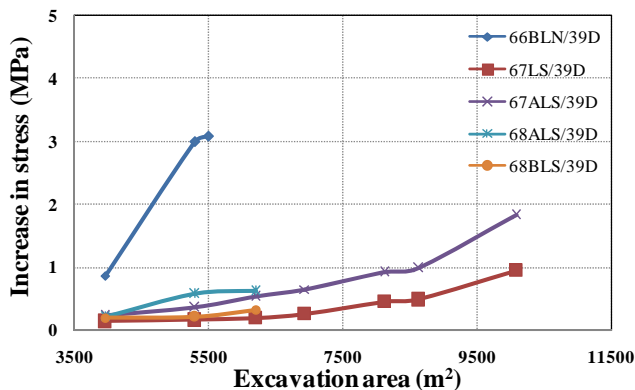


Fig. 8 : Stress recordings with respect to area of extraction in Panel-3B.

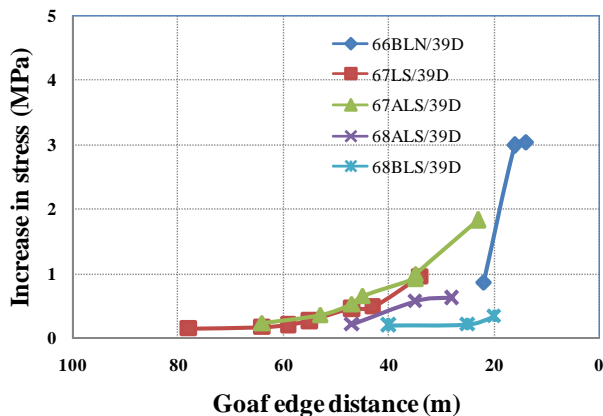


Fig. 9 : Stress recordings with respect to goaf edge distance in Panel-3B.

4.2 Load Variation in the Galleries

The load over O.C. props was recorded during panel extraction. Initial load in all the load cells was maintained 5 t. The change in load was calculated based on final load recorded before the removal of O.C. prop as face approached it. The change in load of O.C. props with respect to area of extraction of Panel-3B is presented in Fig. 10. There was an increase in load of 22 t over O.C. props for the initial area of extraction of about 4000 m² and 32 t for further area of extraction of about 5300 m² in the panel.

Subsequently, noticeable decrease in load of 25 t over O.C. props was observed for further area of extraction about 6200 m². Thus, the sudden decrease in load

observed on O.C. props indicated the occurrence of roof fall in the goaf, due to induced blasting practices. After that, increase in load was observed with respect to area of extraction of 27 t for 7000 m², 28 t for 8000 m², 32 t for 8600 m² and 39 t for 10060 m². These recordings showed regular increase in load, indicating periodic build-up of load on galleries, and increase in load may be due to non-caving of goaf. O.C.

Further O.C. props experienced higher loads in 66AL North, 66BL North, 67L and 67AL South, and load varies from 30 t - 39 t. The panel experienced supports displacements in galleries of 66AL North, 66BL North, 67L and 67AL South.

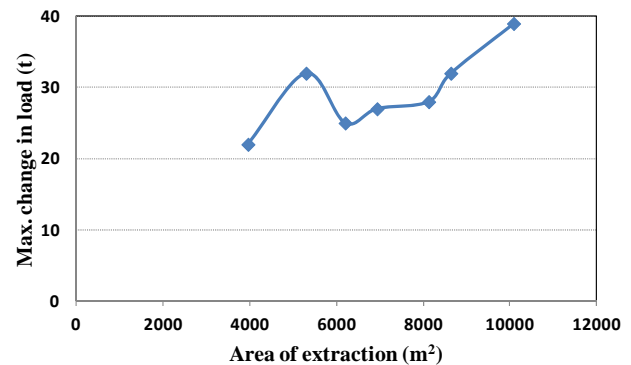


Fig. 10 : Load recordings in galleries in Panel-3B.

4.3 Convergence in Galleries

Roof to floor convergence was monitored at 10 m intervals (i.e. station C1, C2, C3, C4, C5, C6, C7, C8, C9 and C10) from goaf edge in each level of Panel-3B during depillaring.

The convergence in galleries with respect to area of extraction analysed during depillaring in Panel-3B are shown in Fig. 11. Convergence is increasing with area of extraction increased. Results revealed that all the stations that recorded cumulative convergence higher than 100 mm were experiencing large overhangs in goaf even though induced blasting practices in goaf.

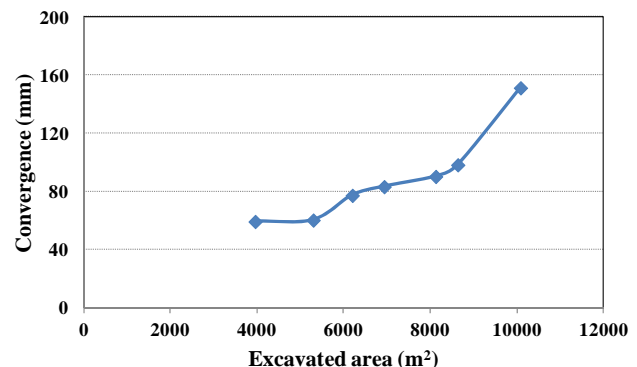


Fig. 11 : Convergence recordings in galleries with respect to area of extraction in panel - 3B.

4.4 Immediate Roof Layers Movement

The trend of immediate roof layer bed separation change recorded in the panel-3B. The maximum bed separation recorded at 68L/39D junction was 3 mm and 0 mm, respectively, in the anchor placed at 7 m and 2m. This indicates that there was no deformation of the immediate coal roof which forms the main roof, whereas, high deformations were recorded in convergence stations may be due to massive sandstone layers overhang.

4.5 Relationship between Change in Stress, load in Galleries and Convergence in the Panel

The recordings obtained from stress cells installed in pillars, convergence in galleries and load cells over O.C. props in galleries of Panel-3B are shown in Fig. 12. All the instruments recording values shown increasing with respective area of extraction in the panel-3B. Generalisation of relationship between stress change in the panel, convergence in galleries and loads on supports may require further studies. Establishing such relationship helps in safely working of the panel.

Further study revealed that the panel experienced heavy spalling and supports displacements in galleries of 66AL North, 66BL North, 67L and 67AL South as shown in Fig. 13 (a, b, c & d).

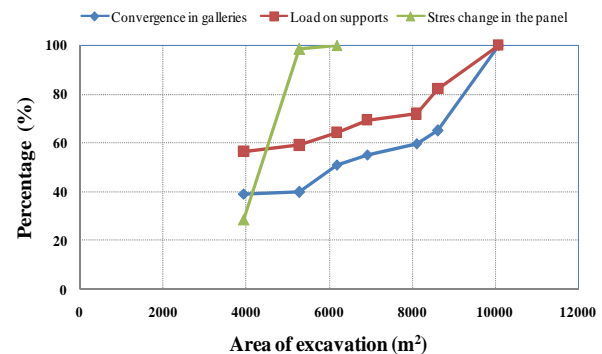


Fig. 12 : Stress change in the panel, convergence in galleries and loads on supports in percentage wise in the panel – 3B



(a)



(b)



(c)



(d)

Fig. 13 : (a, b, c & d) Pillar spalling and support displacements at 66AL to 67L North Pillar

5. CONCLUSIONS

Planning and execution of BG panels requires detailed accounting for rock mass characterisation to be input initially and predict the actual behaviour of panel extraction. Field instrumentation provides vital information during the extraction process for taking necessary decisions and precautions to avoid major obstacles during production. Though planning by various modelling studies provides an insight into the behaviour of panel during extraction, the real-time monitoring facilitates retrieval of valuable information about the behaviour of galleries, pillars and goaf. This study involved extensive field instrumentation to understand the behaviour of strata at different locations within the panel.

Results revealed that the area of extraction was having an influence on front abutment stresses, convergence in galleries and loads on supports ahead of the face. Further, it was observed that, total increase in front abutment stress, about 3.04MPa was noticed when the area of excavation was 6200 m² in the panel. Load on O.C. props increased up to 39 t, indicating transfer of load ahead of face. Galleries experienced maximum cumulative convergence of 151 mm. Convergence in the galleries increases with respective to area of excavation. Tell-tale extensometers indicates that there was no deformation of the immediate coal roof which forms the main roof, whereas, high deformation was recorded in convergence stations may be due to massive sandstone layers overhang.

It may be concluded that when the large overhang in goaf is present, high stress in pillars, high convergence in galleries, high loads in galleries and spalling in pillars is expected. The results obtained from field monitoring studies were quite comparable with the field conditions in BG panel, like spalling in pillars and displacement of supports in galleries. Adoption of field instrumentation in panels could, therefore, be of significant value in assessing the behaviour of BG panels during extraction.

Acknowledgement: Author is thankful to SCCL for carrying out the project and sincere thanks are due to Director, NIRM, for permission to submit the paper in journal.

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MR. DEVENDRA K. SHARMA ASSUMES THE CHARGE OF MANAGING DIRECTOR OF HIMACHAL PRADESH POWER CORPN. LTD.



Mr. Devendra Kumar Sharma, has taken over as Managing Director of Himachal Pradesh Power Corporation Ltd. (A Govt. of Himachal Pradesh Undertaking) in September, 2012. As Managing Director of Himachal Pradesh Power Corporation Ltd., he is responsible for planning, development, engineering, construction and organizing funding for 20 hydroelectric projects having aggregate installed capacity of 3025 MW.

After graduating in Civil Engineering from the University of Indore in 1981, he was awarded the Netherlands Govt. fellowship, in 1982, to pursue Master of Engineering in Water Resources from the Asian Institute of Technology, Bangkok, Thailand. He has done training in hydropower planning and design engineering from Canada (1987), Sweden (1989) and Japan (1994). During the year 1991, he was awarded UNESCO fellowship to complete International Post Graduate Course in Hydrology from the Water Resources Research Institute (VITUKI), Budapest, Hungary. He did courses from the International Centre for Hydropower, Trondheim, Norway as NORAD Scholar in 'Hydropower and the Environment' during 1999 and 'Hydropower Development in the Context of Integrated Water Resources Management' during 2003.

Mr. Sharma has more than 31 years of experience in the field of hydropower in India and abroad. He worked with Himachal Pradesh State Electricity Board in various capacities for approximately twenty four and half years from 1982 to 2006 where he was responsible for planning, investigation, design and monitoring of number of hydroelectric projects like Chamara Stage II (300 MW), Kol Dam (800 MW), Dhamwari Sunda (70 MW), Ghanwi Stage I (22.5 MW), Gaj (10.5 MW), Baner (12 MW) and Thiroit (4.5 MW). He has worked on deputation with SJVNL (formerly NJPC) for Nathpa Jhakri Hydroelectric Project (1500 MW) from 1994 to 1997. He worked in Bhutan on Tala Hydroelectric Project (1020 MW) for construction of dam, diversion tunnel, coffer dams and power intakes for 6 years from 1997 to 2003 where he was awarded "Man of the Year 1999" award for excellence in performance of duties, dedicated services and meritorious contribution in the field of hydropower. After returning from Bhutan during the year 2003, he was responsible for Sawra Kuddu Hydroelectric Project (111 MW) in Pabbar Valley Power Corporation in Himachal Pradesh.

In order to gain experience of working in private sector, he worked with L&T from 2006 to May, 2010, where he completed works of Parbati Stage III (520 MW) and Allain Duhangan (192 MW) Hydroelectric Projects in Himachal Pradesh. From May 2010 to September, 2012, he was responsible for Development of Hydroelectric Projects on BOT basis in India and the neighbouring countries.

Mr. Sharma has presented 26 technical papers and reports in International Conferences/Seminars in India and abroad. He has visited hydropower plants in Thailand, Norway, Sweden, Canada, Japan, Hungary, Austria, Spain, Portugal, Bhutan and Nepal.

Mr. Sharma is life member of various National and International bodies working in the field of hydropower development. He is a member of Governing Council of International Society for Rock Mechanics since 2008 and is Vice President of Indian Society of Rock Mechanics and Tunnelling Technology. He is Governing Council member of Tunnelling Association of India for the year 2011-13. He has represented in Technical and Organizing Committees of various International and National Conferences organized in the field of hydropower.

ISRM (India) wishes him all success for his new assignments.

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Recent Activities of Indian National Group of ISRM

SEMINAR ON “GROUND CONTROL AND IMPROVEMENT”, 20-21 SEPTEMBER 2012, NEW DELHI



Inauguration of the Seminar by Mr. S.P. Kakran, Chairman Central Water Commission



Welcome address by Mr. V.K. Kanjlia, Secretary Central Board of Irrigation & Power

As part of its activities, CBIP, with the support of the Indian National Group of International Society for Rock Mechanics (ISRM, India) and Indian Chapter of International Geosynthetics Society (IGS, India) organized a Seminar on “Ground Control and Improvement” at CBIP Conference Hall, Malcha Marg, Chanakyapuri, New Delhi during 20-21 September 2012.

The objective of the proposed Seminar was to provide a forum for discussion and interaction amongst the participants about the potentially applicable ground improvement methods for civil works structures.

Lectures/Case Histories on the following topics were presented during the Seminar:

- Characterization of Ground
- Preloading and Vertical Drains
- In situ reinforcement Techniques

- Geosynthetics and their applications in Geotechnical & Geoenvironmental Engineering
- Deep Excavation Support Systems
- Grouting Techniques: Permeation, Compaction, Infiltration, Jet Grouting, etc.
- Landslides & Slope Stabilisation Methods
- Soil & Rock Anchors
- Liquefaction & Mitigation Methods

The Seminar was sponsored by PANASIA Project Consultancy Pvt. Ltd. & Wassara and co-sponsored by TechFab (India) Industries Ltd.

The Seminar was attended by 61 delegates from 24 organisations.

The Seminar was inaugurated by Mr. S.P. Kakran, Chairman, Central Water Commission. The inaugural



A view of the participants



Address by Dr. G.V. Roa, Past President Indian Chapter of IGS and Chairman, SAGES



*Presidential Address by Dr. H.R. Sharma,
Chief Technical Principal – Hydro,
Tractebel Engineering Pvt. Ltd.*



*Vote of Thanks by Mr. A.C. Gupta, Director (WR)
Central Board of Irrigation & Power*

session was presided over by Dr. H.R. Sharma, Chief Technical Principal-Hydro, Tractebel Engineering Pvt. Ltd. and President, Indian National Group of ISRM. Dr. G.V. Rao, Former Professor, Department of Civil Engineering, IIT Delhi and Past President of the Indian Chapter of IGS, addressed the gathering too.

Lectures were delivered by the following prominent experts during the Seminar:

- Mr. Michael **Beas**, Wassara, Sweden
- Mr. Shadab .A. **Gadhiya**, TechFab (India) Industries Ltd
- Dr. M.R. **Madhav**, JNT University & IIT Hyderabad
- Dr. K. **Pathak**, IIT Kharagpur
- Dr. V.M. **Sharma**, AIMIL Limited
- Mr. R.K. **Sinha**, National Institute of Rock Mechanics

- Prof. G.L. **Sivakumar Babu**, Indian Institute of Science
- Dr. G.V. **Ramana**, Indian Institute of Technology Delhi
- Dr. G. **Venkatappa Rao**, Sai Master Geoenvironmental Services P. Ltd.

It was concluded that as more and more poor ground conditions were being encountered at many of the infrastructural development project sites, and posing geotechnical challenges, the Seminar on the subject of “Ground Control and Improvement” was aptly chosen. It was stressed that to keep pace with rapid infrastructure development, the concerned had to be prepared to meet the emerging geotechnical challenges and provide superior and cost effective solutions, besides completing the projects in time bound manner.

INTERNATIONAL SEMINAR ON “MINIMIZING GEOLOGICAL UNCERTAINTIES AND THEIR EFFECT ON HYDROELECTRIC PROJECTS”, 27-28 SEPTEMBER 2012, NEW DELHI

There is a broad feeling that hydroelectric projects take longer time than the schedule and the delays are commonly attributed to uncertainties in geological prognostication, without considering the inherent limitations of such studies and the applied methodologies. Accordingly, in order to minimize delays, it is mandatory that the geological and geotechnical assessments are made with greater reliability & precision towards establishment of safe and economic projects. It is therefore important to hold technical forum to deliberate upon the critical issues in addressing problems related to geological & geotechnical concerns towards finding appropriate solutions to overcome the challenges.

In this context, NHPC Limited, in association with Central Board of Irrigation and Power (CBIP), organized an International Seminar on “Minimizing Geological Uncertainties And Their Effect On Hydroelectric Projects”, on 27 and 28 September 2012 at CBIP Conference Hall, Malcha Marg, Chanakyapuri, New Delhi.

The prime objective of the seminar was to discuss issues related to improving upon geological interpretations and supplementation by geotechnical explorations towards formalizing a comprehensive investigation program as well as to bring-forth awareness about the technological advancements and their applications.



Lighting of Lamp by Mr. Devendra Chaudhry



Lighting of Lamp by V.K. Kanjlia

The seminar focused on the issues and challenges in integration of exploratory techniques for improving the reliability of geological assessment, and provided a forum to discuss matters of adoption of appropriate construction methodologies supplemented by contractual provision related to geological information and sharing of risks that are generally issues of concern. During the Seminar, issues related to generating structural geological models for mechanized tunneling sites as well as the selection of TBM types, specific for the site conditions, were discussed.

Following were the topics proposed for discussions during the Seminar:

- Integrating Exploratory Techniques for Reliable Geological Assessment
- Provisions for Looking Ahead in Critical Areas in Construction
- Importance of Slope Stability in Hydroelectric Projects
- Role of Geology in Deployment of TBM

More than 140 delegates from India and abroad participated in the Seminar.

During the Inaugural Session, Mr. D.P. Bhargava, Director (Technical), NHPC Limited, welcomed the dignitaries on the dais and the participants.

Mr. A.S. Bakshi, Chairperson, Central Electricity Authority, in his address mentioned that geological uncertainties and unexpected strata encountered during construction of tunnels and underground works of hydropower projects, especially the large ones, result in unforeseen problems, increased quantities of execution, and time & cost overruns. He expressed the hope that project developers, contractors, consultants, engineers, suppliers, researchers who were attending the seminar would be greatly benefited from deliberations regarding the state-of-art technology and modern methodology in overcoming challenges occurring due to geological uncertainties during the construction of hydroelectric projects and thus minimize the cost overruns.

Mr. Devendra Chaudhry, Additional Secretary to Government of India, Ministry of Power, mentioned that Hydro Electric Projects having about 6000 MW potential were affected by geological problems at present, and expressed the hope that the very purpose of the Seminar would be not just to address a very large interesting and wider range of issues, but the focus should be to address what were the problems in those projects.



Mr. A.S. Bakshi addressing the participants



A view of the audience



Welcome address by Mr. D.P. Bhargava



Mr. Devendra Chaudhry addressing the participants

Mr. R.P. Singh, Chairman and Managing Director, SJVN Limited in his address mentioned that when we look back upon the development of Hydro Power in general in our country in the past, it is observed that barring a few projects, all of them have suffered significant time and cost over-run and the major reason cited for it is wide variance between geology predicted at the DPR stage and as actually encountered during the construction of underground works, and expressed hope that the elite gathering present in the Seminar would be sharing the latest development in the geological exploration field which would definitely help all the developers in having better understanding of geology.

The keynote address on “Minimizing Geological Uncertainties and their Effects on Hydroelectric Projects” was delivered by Mr. M. Gopalakrishnan, Former Secretary General, ICID, before the commencement of the technical sessions. Mr. M. Gopalakrishnan emphasized need for issues like cost of investigations, time frame required for planning to Design stage nature of tender documents. He mentioned that the Hydro Power sector should not be singled out for failures as failures had been observed all over the world and in case of tunnels in other sectors such as transportation sector.

The presentations on the following topics were made and discussed during the Seminar:

- Geological Investigations – Challenges & Success - Mr. A.S. Walvekar, Executive Director (Geo-Tech), NHPC Limited
- Geotechnical Monitoring-Contribution to Risk Management - Dr. Florian Krenn, Managing Director, Geoconsult India Pvt. Ltd.
- Optimum Exploration for a Bankable Detailed Project Report - Mr. Prasanta Mishra, Director, Geological Survey of India
- Importance of Rock Mechanic Studies in Site Characterization towards Minimizing Uncertainties -

Dr. V. M. Sharma, Director, AIMIL Ltd.

- Prognostic Geological Explorations for Minimizing Geological Uncertainties - Dr. Gopal Dhawan, Chairman and Managing Director, Mineral Exploration Corporation Limited
- Minimizing Geological Uncertainties during the Execution Phase - Mr. Wolfgang Holzleitner, COO, Bernard Gruppe, Germany
- Integrating Exploration and Preparation of Baseline Report - Dr. Dinesh Sati, Consulting Geologist, THDC India Limited
- Geological Assessment through Integrated Approach – Mr. Umesh.V. Hegde, Executive Director-Engg. Geology & Geotech, Lanco Infratech Limited
- Geological Uncertainties-Site Specific Challenges and its Management - Mr. Manoj Basu, General Manager (Geology), NHPC Limited
- Contractual Problems due to Geological Uncertainties and Possible Remediation through Contract – Mr. V.K. Kapoor, President-Projects, Bhilwara Energy Ltd.



Mr. M. Gopalakrishnan, Former Secretary General, ICID, delivering Keynote lecture

- Managing Risk due to Geological Uncertainties in Hydropower Projects - Mr. Eckhard Kleine, Sales Engineer, Herrenknecht AG, Germany
 - Geological Prognostication during Mechanized Tunneling – Dr. G.W. Bianchi, Senior Engineering Geologist, SEA Consulting s.r.l.
 - Application of Tunnel Seismic Prediction in Varied Geological Conditions - Dr. T. Dickmann, Unit Manager-Geophysics, Amberg Technologies AG, Switzerland
 - Minimizing Geological Uncertainties through Mitigating Measures at Nathpa-Jhakri Project – Mr. Deepak Nakhasi, General Manager (Civil Design), SJVN Limited
 - Geotechnical Prognostication during Construction – Dr. Rajbal Singh, Scientist, Central Soil and Materials Research Station
 - Role of Geology and Special Rock Mechanic Tests in TBM Tunnelling-A Perspective – Dr. V.M.S.R. Murthy, Professor, Department of Mining Engineering, Indian School of Mines
 - Concurrent Evaluation & Measures Adopted While Tunneling Through TBM – Mr. Michele A. Sposetti, India Projects Coordinator, S.E.L.I. Tunnelling (India) Private Limited
 - Important Aspects for Geological Assessment in TBM Selection- Case history - Mr. M.M. Madan, Director, GVK Group
 - Current Practices in Ground Improvement and support Measures in TBM driven Tunnels through Difficult Geological Conditions - Mr. James Clark, Projects Manager India, The Robbins Company
 - Slope Stability-Issues and Management – Mr. Balraj Joshi, General Manager, NHPC Limited
 - Identification of Potential Slides and Support Systems – Dr. R. Chitra, Scientist, Central Soil and Materials Research Station
- The Seminar concluded with Panel Discussions, with following panel of experts:
- Dr. H.R. Sharma (Chairman), Chief Technical Principal-Hydro, Tractebel Engineering Pvt. Ltd.
 - Dr. V.M. Sharma, Director, AIMIL Ltd.
 - Dr. Prabhas Pande, Former ADG, Geological Survey of India
 - Mr. R.N. Misra, Director (Civil), SJVN Ltd.
 - Dr. Florian Krenn, Managing Director, Geoconsult India Pvt. Ltd.
 - Mr. A.S. Walvekar, Executive Director (Geotech.), NHPC Ltd.
- The panel of experts after having an overview of all technical sessions initiated discussions within the house. Subsequent to various deliberations in the open house, draft recommendations were made.

SEMINAR ON “SLOPE STABILIZATION CHALLENGES IN INFRASTRUCTURE PROJECTS”,

29-30 NOVEMBER 2012, NEW DELHI

As part of its activities, the Central Board of Irrigation & Power (CBIP), with the support of the Indian National Group of International Society for Rock Mechanics (ISRM, India) and Indian Chapter of International Geosynthetics Society (IGS, India) organised a Seminar on “Slope Stabilization Challenges in Infrastructure Projects” at Central Board of Irrigation and Power, Malcha Marg, Chanakyapuri, New Delhi on 29 and 30 November 2012.

The objective of the proposed Seminar was to provide a forum for design and construction engineers for analyzing the stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock, methods for analysis of slope stability, strength tests, analysis conditions, and factors of safety, use of geosynthetics for slope stability, etc.

The Seminar was inaugurated by Mr. R. Jeyaseelan, Former Chairman, Central Water Commission. The Inaugural Session was presided over Dr. T. Ramamurthy, Visiting Professor, Department of Civil Engineering, IIT Delhi.

Mr. A.C. Gupta, Director (WR), CBIP, in his welcome address stressed on the need to provide adequate drainage which, in general, shall help in minimizing failure of soil/rock slopes. He requested participants to have useful interaction during the Seminar.

Dr. A.K. Dhawan, Chief Consultant, Fugro Geotech Pvt. Ltd., and Former Director, Central Soil and Materials Research Station and Seminar Coordinator briefly described the objectives of the Seminar during the Inaugural Session.



*A view of the dais during inaugural session (L to R):
Dr. A.K. Dhawan, Dr. T. Ramamurthy, Mr. R. Jeyaseelan
and Mr. A.C. Gupta*



*Panel Discussions (L to R): Mr. S.K. Raina, Mr. J.N.L. Das,
Dr. T. Ramamurthy, Mr. R.K. Vishnoi and Mr. A.C. Gupta*

In total, 40 participants from 26 organizations participated in the Seminar.

Following papers were presented and discussed during the Seminar:

- Slope Stability - Lesson from Failures Encountered – Mr. R. Jeyaseelan, Former Chairman, Central Water Commission
- Stability Problems in Natural and Manmade Slopes – Dr. A.K. Dhawan, Chief Consultant, Fugro Geotech Pvt. Ltd., and Former Director, Central Soil and Materials Research Station
- Role of Geoinformatics in Slope Stability Assessment and Monitoring – Dr. P.K. Champati Ray, Head, Geosciences and Geohazards Department, Indian Institute of Remote Sensing, ISRO, Dehradun
- Slope Stability in Open Pit Mines- Theory and Practice – Dr. V.K. Singh, Deputy Director & Head, Slope Stability Division, Central Institute of Mining & Fuel Research
- Geosynthetic Hybrid Drain System for Improving Fine Grained Soil – Dr. Chandan Ghosh, Professor & Head (Geohazards), National Institute of Disaster Management
- Slope Stability using Gabions and related Flexible Engineering Materials – Ms. Minimol Korulla, Chief Technical Officer, Maccaferri Environmental Solutions Pvt. Ltd.
- Slope Stabilization Challenges - Significance of Analysis for Effective Solutions – Mr. R.K. Vishnoi, AGM, THDC India Limited
- Stability Analysis of Slopes – Dr. R. Chitra, Scientist E, Central Soil and Materials Research Station

- Design and Development of Improved Varieties of Open Weave Jute Geotextiles for Erosion Control – Mr. P.K. Choudhury, In-Charge, Geotech Cell, Indian Jute Industries' Research Association

The Seminar concluded with the panel discussions on 30 November 2012 under the Chairmanship of Prof. T. Ramamurthy. Mr. S.K. Raina, Executive Director, Chenab Valley Power Projects (P) Limited, Mr. J.N.L. Das, Chief Track Engineer, Ministry of Railways Mr. R.K. Vishnoi, AGM, THDC India Ltd. and Mr. A.C. Gupta, Director (WR), CBIP, participated in the Panel Discussions as panelist. During the session, participants discussed the problem being faced in the professional engagements and provided their feedback about the Seminar.

Some of the points which emerged during the deliberations of the Seminar are as under:

- Construction of any infrastructure in a slide prone area should be carried out only after gathering enough geological data of that area. A powerful database comprising of information about disaster prone hill ranges should be maintained
- Keeping in view that at DPR stage it may not possible to do the requisite or adequate investigation of soil/rock mass due to various site constraints or some other reasons, it is desirable that during execution wherever there is element of doubt, rock strata or soil mass is to be tested for the requisite properties so as to take mid course correction for slope stabilization measures.
- Surface as well as sub-surface Drainage are the best preventive measure for mitigation rock/soil slide



A view of the participants

- Deep drainage holes are preferred over weep holes in retaining walls for effective slope stabilization. Providing proper drainage measure is key to success.
- Roots of Vegetation form an anchor for soil and help reduce amount of water in pore spaces. Aforestation should be encouraged to as it can help in slope stabilization. under all conditions.
- Mapping of old slide zones using remote sensing data shall be useful for taking preventive action as these slides can activate any time and may cause heavy damage to man and properties. Geoinformatics tools and technique(GIT) can supplement the traditional methods of observation by providing timely and reliable information at relatively lower cost
- Flexible retaining walls using gabions are useful and often preferable over non flexible retaining walls for slope stabilization.
- HYBRID system consisting of thin sand mat at both sides of geocomposite is found to be efficient against clogging.
- Jute Textile (JGT) plays a more effective role in restraining surface soil erosion than the conventional varieties of Open Weave Jute Geotextile (OWJGT) of identical weights.
- Man-made GTs appears to be less effective because of its thinness apart from its inability to create a congenial micro-climate that facilitates vegetation growth.
- For Open cast mining, it is desirable from slope stability considerations to dump the waste material at a safe distance rather than at the top level near the cut slope.

ISRM SPONSORED FORTHCOMING EVENTS

- 20-22 May, 2013, Brisbane, Australia - *Effective and Sustainable Hydraulic Fracturing* - an ISRM Specialized Conference
- 18-20 June 2013, Shanghai, China - SINOROCK 2013 - *Rock Characterization, Modelling and Engineering Design Methods* – an ISRM Specialized Conference
- 20-22 August 2013, Sendai, Japan - *The 6th International Symposium on Rock Stress* - an ISRM Specialized Conference
- 21-26 September 2013, Wroclaw, Poland - *EUROCK 2013 - Rock Mechanics for Resources, Energy and Environment* - the 2013 ISRM International Symposium
- 26-28 May 2014, Vigo, Spain - *EUROCK 2014 - Rock Engineering and Rock Mechanics: Structures in and on Rock Masses* – an ISRM Regional Symposium
- 15-17 October 2014, Sapporo, Japan - *ARMS 8 - 8th Asian Rock Mechanics Symposium* - The 2014 ISRM International Symposium
- 10-13 May 2015, Montréal, Canada - ISRM 13th International Congress on Rock Mechanics
- 7-9 October 2015, Salzburg, Austria - *EUROCK 2015 – Geomechanics Colloquy* - an ISRM Regional Symposium

ISRM NEWS

ISRM 50-years anniversary celebrations closed in October in Salzburg, at the Geomechanics Colloquy

The celebrations of the 50-years anniversary of the ISRM started in October 2011 in Beijing, during the 12th ISRM Congress, had a peak during the EUROCK 2012 in Stockholm, last May, and symbolically closed in October 2012 during the 61st Geomechanics Colloquy in Salzburg, the same city where ISRM was founded, in 1962.

A number of activities took place during this year of celebrations:

- A competition, open to ISRM members, to create the 50th anniversary logo, which was used throughout the year of 2012, won by our member Dr Ludger Suarez-Burgoa.
- A competition open to young members of the ISRM to present their vision of "The Future Directions for Engineering Rock Mechanics", won by Dr Ricardo Resende.
- A 50th anniversary commemorative banquet held during the ISRM Congress in Beijing on 21 October 2011, where Dr Nuno Grossmann made a presentation on the life of the Society during its first 50 years.
- The publication of the "ISRM 50th Anniversary Commemorative Book - 1962-2012", edited by Prof. John Hudson and Dr Luís Lamas. This book has been compiled to celebrate ISRM's 50-year anniversary by outlining the background to the formation of the ISRM and the most significant activities during the 50 years. It includes contributions from the living Past Presidents of the ISRM and from the Regional Vice Presidents. This full colour book, with 200 pages, can be purchased from the ISRM Secretariat.
- A Historical Exhibition including six panels describing the main milestones in the development of the ISRM during these 50 years, starting with the constitutional meeting on 25 May 1962 in Salzburg and the First Congress in Lisbon in 1966. Reference is made to the main technical achievements, namely through the ISRM Commissions and Congresses, to the most important publications and to the main technical concerns of the Society along the years. The evolution of the membership and the location



International Society for Rock Mechanics

of the venues of the ISRM conferences are also presented.

- The Commemorative Book and the Historical Exhibition were displayed at all the ISRM conferences of 2012, at the 46th U.S. Rock Mechanics Symposium and also at the 61st Geomechanics Colloquy, in Salzburg.
- A commemorative session at the Geomechanics Colloquy in Salzburg, with the presence of Dr Franz Pacher, one of the founders of the ISRM,



Closing session of the 50th anniversary celebrations in October 2012, in Salzburg, during the 61st Geomechanics Colloquy: addresses by Prof. Wulf Schubert, Dr Nuno Grossmann and Prof. Xia-Ting Feng.



Dr Franz Pacher—that together with Prof. Leopold Müller put forward the idea of creating the ISRM—gave an interview allusive to the foundation of the ISRM and was present at the commemorative ceremony.

A Tribute to John Franklin, 1940-2012

Professor John Franklin passed away on 6 July, after a prolonged illness that he fought with unparalleled strength and courage. Those who attended the ISRM Congress in Beijing, last October, where John received his Fellowship of the ISRM, can confirm his perseverance and dedication to our Society until the limit of his capacities.



For the Geo-engineering community and for the ISRM in particular this is a very sad moment. Geo-engineering at large is poorer. John Franklin was a top scientist, a successful practitioner, a strong leader and a marvelous person. Those who had the privilege to know him will never forget his dedication, his capacity to

motivate people, his brilliant mind and his insurmountable capacity to discover new research themes, or new working methods. He was and will remain a guide for younger generations.

Of his lifetime accomplishments, he was most proud of his association with the ISRM. He served as ISRM President (1987-1991) and Chairman of the ISRM Commissions on Testing Methods (1975-1987) and Education (1991-1995). Among his uncountable contributions to our Society, John has organised and directed the preparation of most of the ISRM "Suggested Methods" for rock testing.

ISRM Franklin Lecture instituted to honour the memory of late Past President Professor John Franklin

The ISRM Board decided to institute the ISRM Franklin Lecture to honour the memory of Professor John Franklin (1940-2012), President of the International Society for Rock Mechanics from 1987 to 1991. Among his uncountable contributions to our Society, John Franklin has organised and directed the preparation of most of the ISRM "Suggested Methods" for rock testing.

The purpose of the ISRM Franklin Lecture is to recognise a mid-career ISRM member who has made a significant contribution to a specific area of rock mechanics and/or rock engineering. It will be given in every year, at the ISRM International Symposium, except for those years when the 4-yearly ISRM Congress is held. This lecture will replace the existing ISRM annual lecture.

Click here to read the Guideline for the Franklin Lecture.

The ISRM Franklin Lecturer will be selected by the Board. He shall be based in the region where the ISRM International Symposium is being held that year, and will

be required to give a keynote presentation on the subject of his/her expertise.

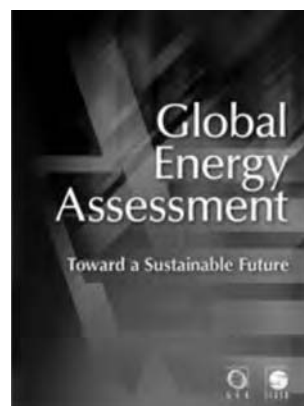
The ISRM Franklin Lecture will be published in the ISRM News Journal.

The 2013 ISRM Franklin Lecture will be given in Wroclaw, Poland, during the 2013 International Symposium, by Dr. Andreas Goricki from Austria.

A massive Global Energy Assessment Study Involved Experts from Around the World

The International Institute for Applied Systems Analysis (IIASA) in Austria has completed a massive Global Energy Assessment study involving experts from around the world. The report is available for downloading at the following site: http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/Chapters_Home.en.html.

One of our ISRM Members, Dr Maurice Dusseault, and his graduate student Ali Shafiei, contributed important sections related to non-conventional petroleum energy sources, with a focus on viscous oil production methods and environmental issues. Dr Dusseault is the President of the Petroleum Geomechanics Commission of the ISRM, and the contributions that he has made to heavy oil development engineering have been related to his training and experience in Rock Mechanics.



Dr Dusseault and Ali Shafiei also recently contributed a new Chapter on Oil Sands for the well-known Ullmann's Encyclopedia of Industrial Chemistry, an industry standard knowledge base published by Wiley: *Dusseault MB, Shafiei A. 2011. Oil Sands. Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. 52 pages.* This chapter evaluates world oil sand resources and summarizes many aspects of resource magnitude and production approaches.

Maurice Dusseault

[Go to the top of the Newsletter](#)

ISRM Online Lectures Series: A New Initiative to Start in February 2013

The ISRM Board has discussed a number of initiatives to be implemented in the short term, in order to give more benefits to the members and to serve better the



rock mechanics community. One of them, which will start very soon, is the ISRM Online Lectures Series. Experts in different fields of rock mechanics will be invited to give a lecture on a specific topic. Each lecture will be broadcast from the ISRM website at a predefined date and time, and the attendees will be able to ask questions to the

lecturer by e-mail, on the topic of the lecture, during the subsequent 48 hours. The ISRM Online Lectures will remain available on the ISRM website in a dedicated webpage.

Our plans are to organise four Online Lectures per year. The first one will be broadcast on 19 February, at 10 a.m. GMT, and it will remain online so that those those unable to attend at this time will be able to do it later. In order to know what is the correspondence between GMT and your local time, just look for GMT in your Internet search engine.

For the first Online Lecture the ISRM President decided that it would be a good opportunity to listen to the developments in the well-known New Austrian Tunnelling Method, now that it formally completed 50 years of existence. The invited speaker will be Prof. Wulf Schubert from Austria, and the title of his lecture will be "50 years NATM - from a construction method to a system".

Prof. Schubert is head of the Institute for Rock Mechanics and Tunnelling at the Graz University of Technology, where he teaches in the Bachelor and Master program, as well as in the post-graduate course "NATM Engineer". Under his guidance about 70 Master theses and 20 PhD theses have been prepared. Besides the University activities he consults on international projects as a partner of 3G - Gruppe Geotechnik Graz Consulting Engineers. He served as Vice President at Large for the ISRM from 1999 to 2003 and is President of the Austrian Society for Geomechanics since 2007.

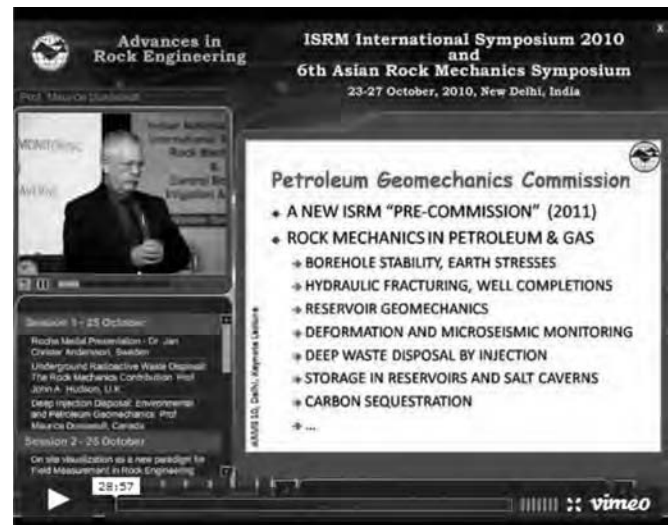
New Delhi Asian Rock Mechanics Symposium Keynote Lectures Now Online

The videos and presentations of the keynote lectures of the 2010 ARMS held in New Delhi, India are now online. ISRM members can watch the full length lectures, which are accompanied by the powerpoint presentations:

- Jan Christer Andersson, Rocha Medal Winner - Äspö Pillar Stability Experiment
- John A. Hudson - Underground Radioactive Waste Disposal: The Rock Mechanics Contribution
- **Maurice Dusseault - Deep Injection Disposal: Environmental and Petroleum Geomechanics**

- Shinichi Akutagawa - On Site Visualization as a New Paradigm for Field Measurement in Rock Engineering
- Herb Wang - Deep Underground Instrumentation and Monitoring
- Giovanni Barla - Progress in the Understanding of Deep-Seated Landslides from Massive Rock Slope Failure
- Yossef H. Hatzor - Modelling Dynamic Deformation in Natural Rock Slopes and Underground Openings with Numerical DDA Method
- Claus Erichsen - Challenges in the Design and Construction of Tunnels in Jointed Rock
- Guowei Ma and Yingxin Zhou - Rock Dynamics Research in Singapore: Fundamentals and Practices
- Xia-Ting Feng - Application of Intelligent Rock Mechanics Methodology to Rock Engineering
- John Read - The Large Open Pit Project

Wudongde Hydropower Station - A New 10,200 MW Hydropower Project



- The Wudongde hydropower station, located at the downstream segment of Jinsha River has an installed 10,200MW electric capacity. It consists of one dam and two underground cavern hinges. The dam is a typical hyperboloidal arch concrete dam with the maximum height in 265m. There are five table holes, six mid holes and two spillway tunnels in this dam.
- The left underground hydraulic caverns include main powerhouse, main transformers cavern, six busbar tunnels, tailwater lock chamber, six pressure pipes, and six tailwater tunnels. The size of main powerhouse is about 321.0m in length, 31.8m in width

and 86.9m in height. The main transformers cavern, which is parallel to the main powerhouse and is 45m in distance with main powerhouse, is about 255.6m in length, 18.5m in width and 34.5m in height. The axes direction of main powerhouse and main transformers cavern is NE42° in trend, which intersects the trend of rock stratum with 45°. The underground hydraulic hinge in right bank has the same structure of left underground hydraulic. The axes direction of main power and main transformed cavern is NE70°, which intersects the trend of rock stratum with 10°.

- The rock stresses around the left and ground underground caverns is shown in the following table.



Fig. 1 : Layout of Wudongde hydraulic project

Underground caverns	Statistic	Principal stress σ_1			Principal stress σ_2		
		Value (MPa)	Dip angle (°)	Trend angle (°)	Value (MPa)	Dip angle (°)	Trend angle (°)
Left	Range	11.3-14.9		40-70 210-270	5.2~8.2		300-340 120-140
	Max.	14.9	68		9.6	41	
	Min.	11.3	7		5.2	5	
	Average	13.3	41.4		6.8	24.6	
Right	Range	5.6-13.0		290-340 120-180			50-100 300-360
	Max.	13.0	88		6.4	80	
	Min.	5.6	4		2.9	2	
	Average	7.2	56.9		4.0	12.9	

- The folded stratum in this region is slight metamorphic limestone and marble and sedimentary dolomite with the dip angle of 50~80°, as can be seen in Fig.3.

Thus, during the excavation of underground tunnels or caverns, falling of surround rock occurred frequently, as shown in Fig.4.



Fig.2 : The Jinsha River and banks collapse in the diversion tunnel



Fig.3 : Steep dip stratum in diversion tunnel



Fig.4 : Rock

The 2014 ISRM International Symposium will take place in Japan

The ISRM Council has selected Sapporo, Japan, as the venue of the 2014 ISRM International Symposium, following a vote by secret ballot between Eurock 1014 in Vigo, Spain, and ARMS 8.

ISRM Rocha Medal 2013

The ISRM Board decided at its Tokyo meeting in September 1981, to institute an annual prize with a view to honour the memory of Past-President Prof. Manuel Rocha. Profiting from the basis established by Prof. Müller, Prof. Rocha organized the first ISRM Congress and he was the leader that was responsible for transforming the international collaboration carried out in an amateurish way into a real international scientific association, having for the purpose settled the fundamental lines that have guided and supported the ISRM activity along the years.

The Rocha Medal is intended to stimulate young researchers in the field of rock mechanics. The prize, a bronze medal and a cash prize, have been annually awarded since 1982 for an outstanding doctoral thesis selected by a Committee appointed for the purpose.

The ISRM Board has decided to award the Rocha Medal 2013 to Dr Mathew Pierce from Canada for the thesis "A model for gravity flow of fragmented rock in block caving mines" presented at the University of Queensland, Australia. He will receive the award at the 2013 ISRM International Symposium in Wroclaw, Poland.

Two runner-up certificates were also awarded to Dr He Lei, from China, for the thesis "Three dimensional numerical manifold method and rock engineering applications" presented at the Nanyang Technological University, Singapore, and to Dr Andrea Perino, from Italy, for the thesis "Wave propagation through discontinuous media in rock engineering" presented at the Politecnico di Torino, Italy.

"Hydrogeology for Rock Engineers" by Gunnar Gustafson published by BeFo with ISRM sponsorship

The book "Hydrogeology for Rock Engineers" by Gunnar Gustafson, originally written in Swedish, was translated into English and published by BeFo, the Swedish Rock Engineering Research Foundation, with ISRM sponsorship. The book can be purchased from BeFo.

Groundwater has become a problem in construction of tunnels and other underground facilities in a way it has

never been before. Tighter environmental regulations mean that documentation of a completely different calibre is now required when applying for permission to construct an underground facility. Greater requirements for a dry environment in road and railway tunnels have increased demands on sealing and drainage. Existing tunnels in metropolitan areas largely drain the rock of the available groundwater, and new underground constructions and tunnels can exacerbate the situation. Naturally, the traditional problems relating to groundwater remain, making construction difficult in water-conducting zones in poor-quality rock, and involving the risk of settlement if clay layers overlying the rock are drained.

This book provides a review of our current knowledge about the hydro-geology of the crystalline basement, and explains how this can be applied in practical methods for use in site investigations, layout and design, as well as in the operation of tunnels and underground facilities. The work is based on research and practical experience of hydrogeological problems and phenomena. Much of the knowledge base comes from the SKB research and pre-investigation studies relating to final disposal for spent nuclear fuel. However, the aim is not to describe the research front as such, but rather to explain what is important and useful for the rock construction community in general.

ISRM Communication

The website continues to be the main source of information about the Society and most benefits are offered to the members in a password protected members' area. Members can now download their membership certificates in pdf format.

The digital newsletter is sent to all ISRM members and subscribers every 3 months. It includes news about the society and other news of interest to rock mechanics. Contributions are welcome with short news on issues of general interest.

The latest issue of the **News Journal**, edited by Prof. John Hudson and Prof. Xia-Ting Feng, has 80 pages and contains the annual review of the Society's activity along 2011 and technical articles such as a summary of the 6th Müller Lecture. It has been posted on the website where it can now be read online or it can be downloaded.

The **Digital Library**, hosted by OnePetro.org, continues to be updated with papers from more ISRM sponsored conferences. It has now 22 conferences, with over 25,000 pages. Members can download 100 papers per year at no cost.

Recipients of the Rocha Medal

1982	A.P. Cunha	PORTUGAL	Mathematical Modelling of Rock Tunnels
1983	S. Bandis	GREECE	Experimental Studies of Scale Effects on Shear Strength and Deformation of Rock Joints
1984	B. Amadei	FRANCE	The Influence of Rock Anisotropy on Measurement of Stresses in Situ
1985	P.M. Dight	AUSTRALIA	Improvements to the Stability of Rock Walls in Open Pit Mines
1986	W. Purrer	AUSTRIA	Calculation Model for the Behaviour of a Deep-Lying Seam Roadway in a Solid (but cut by Bedding Planes) Surrounding Rock Mass, taking into Consideration the Failure Mechanisms of the Soft Layer Determined In-Situ on Models
1987	D. Elsworth	UNITED KINGDOM	Laminar and Turbulent Flow in Rock Fissures and Fissure Networks
1988	S. Gentier	FRANCE	Morphology and Hydromechanical Behaviour of a Natural Fracture in a Granite, under Normal Stress – Experimental and Theoretical Study
1989	B. Fröhlich	GERMANY	Anisotropic Swelling Behaviour of Diagenetically Consolidated Claystones
1990	R.K. Brummer	SOUTH AFRICA	Fracturing and Deformation at the Edges of Tabular Gold Mining Excavations and the Development of a Numerical Model describing such Phenomena
1991	T. H. Kleine	AUSTRALIA	A Mathematical Model of the Rock Breakage by Blasting
1992	A. Ghosh	INDIA	Fractal and Numerical Models of Explosive Rock Fragmentation
1993	O. Reyes W.	PHILIPPINES	Experimental Study and Analytical Modelling of Compressive Fracture in Brittle Materials
1994	S. Akutagawa	JAPAN	A Back Analysis Program System for Geomechanics Application
1995	C. Derek Martin	CANADA	The Strength of Massive Lac du Bonnet Granite around Underground Openings
1996	M. P. Board	USA	Numerical Examination of Mining-Induced Seismicity
1997	M. Brudy	GERMANY	Determination of In-Situ Stress Magnitude and Orientation of 9 km Depth at the KTB Site
1998	F. MacGregor	AUSTRALIA	The Rippability of Rock
1999	A. Daehnke	SOUTH AFRICA	Stress Wave and Fracture Propagation in Rock
2000	P. Cosenza	FRANCE	Coupled Effects between Mechanical Behaviour and Mass Transfer Phenomena in Rock Salt
2001	D. F. Malan	SOUTH AFRICA	An Investigation into the Identification and Modelling of Time-Dependent Behaviour of Deep Level Excavations in Hard Rock
2002	M.S. Diederichs	CANADA	Instability of Hard Rockmasses: the Role of Tensile Damage and Relaxation
2003	L. M. Andersen	SOUTH AFRICA	A Relative Moment Tensor Inversion Technique applied to Seismicity Induced by Mining
2004	G. Grasselli	ITALY	Shear Strength of Rock Joints based on the Quantified Surface Description
2005	M. Hildyard	UNITED KINGDOM	Wave Interaction with Underground Openings in Fractured Rock
2006	D. Ask	SWEDEN	New Developments of the Integrated Stress Determination Method and Application to the ÅSPÖ Hard Rock Laboratory, Sweden
2007	H. Yasuhara	JAPAN	Thermo-Hydro-Mechano-Chemical Couplings that Define the Evolution of Permeability in Rock Fractures
2008	Z.Z.Liang	CHINA	Three Dimensional Numerical Modelling of Rock Failure Process
2009	Li Gang	CHINA	Experimental and Numerical Study for Stress Measurement by Jack Fracturing and Estimation of Stress Distribution in Rock Mass

2010	J. Christer Andersson	SWEDEN	Rock Mass Response to Coupled Mechanical Thermal Loading. Äspö Pillar Stability Experiment, Sweden
2011	D. Park	KOREA	Reduction of Blast-Induced Vibration in Tunnelling Using Barrier Holes and Air-deck
2012	M.T. Zandarin	ARGENTINA	Thermo-Hydro-Mechanical Analysis of Joints - A Theoretical and Experimental Study

Rocha Award Runner Up Certificates

2010	Yoon Jeongseok	KOREA	Hydro-Mechanical Coupling of Shear-Induced Rock Fracturing by Bonded Particle Modeling
2010	Abbas Taheri	IRAN	Properties of Rock Masses by In-situ and Laboratory Testing Methods
2011	Bo Li	CHINA	Coupled Shear-flow Properties of Rock Fractures
2012	B.P Watson	SOUTH AFRICA	Rock Behaviour of the Bushveld Merensky Reef and the Design of Crush Pillars
2012	J. Taron	USA	Geophysical and Geochemical Analyses of Flow and Deformation in Fractured Rock

NEWS FROM INDIAN NATIONAL GROUP OF ISRM

NOMINATION FROM INDIA FOR ISRM COMMISSION ON EDUCATION

ISRM Commission on "Education" is one of the commissions on various subjects. The purpose of the Commission is to organize activities and enhance teaching and training level of education on rock mechanics.

Prof. Meifeng Cai, College of Resources Engineering, University of Science & Technology Beijing, is the President of the Commission. The other members of the commission are:

- M. A. Kwasniewski (Poland)
- N. F. Grossmann (Portugal)
- M. U. Ozbay (USA)
- J.P. Harrison (Canada)
- J.A. Wang (China)
- F. Pellet (France)
- L. Jing (Sweden)
- J. Zhao (Switzerland)
- Xia-Ting Feng (ex officio), ISRM President
- Yingxin Zhou (ex officio) ISRM Vice President (Asia)

ISRM requested the Indian National Group to nominate a key person who is working at Indian University to be a member of ISRM Commission on Education.

Prof. K.G. Sharma, Department of Civil Engineering, IIT Delhi, has been nominated as member of the Commission from India considering his exposure to teaching of rock mechanics, both at Undergraduate and Postgraduate levels.

PUBLICATIONS OF INDIAN NATIONAL GROUP OF ISRM

Proceedings of the 6th Asian Rock Mechanics Symposium on “Advances in Rock Engineering”

India is a fast developing economy requiring large scale infrastructure. Successive five year plans of Government of India have provided the policy frame work and funding for building up its wide infrastructure and manpower. Rock Engineering does play an important role in most of infrastructure developmental activities related to civil engineering works. The need therefore is to keep ourselves abreast with the latest development in the field of rock engineering and its related fields such as design and construction of underground works, foundation of dams, slope stability etc.

Keeping this in view, ISRM International Symposium and the 6th Asian Rock Mechanics Symposium on “**Advances in Rock Engineering**” was jointly organized by the Indian National Group of ISRM and Central Board of Irrigation and Power, in New Delhi during 25-27 October 2010.

The proceedings of the Symposium contains extended abstracts of 166 papers from 27 countries selected for oral and poster presentations on the following topics:

- Testing and Modelling of Rocks & Rock Masses
- Slope Stability: Analysis & Design
- Foundations
- Underground Structures: Analysis, Design & Construction
- Artificial Intelligence
- Flow and Contaminant Transport
- Rock Dynamics
- Techniques for Improvement of Quality of Rock Mass
- Instrumentation and Monitoring

In addition, the proceedings contains the full texts of the following keynote lectures delivered by renowned experts from Australia, Canada, China, Israel, Italy, Japan, Singapore, U.K. and USA:

- On Site Visualization as a New Paradigm for Field Measurement in Rock Engineering
- Progress in the Understanding of Landslides from Massive Rock Slope Failure
- Deep Injection Disposal: Environmental and

Petroleum Geomechanics

- Application of Intelligent Rock Mechanics Methodology to Rock Engineering
- Modelling Dynamic Deformation in Natural Rock Slopes and Underground Openings with Numerical DDA Method
- Underground Radioactive Waste Disposal -- The Rock Mechanics Contribution
- Rock Dynamics Research in Singapore: Fundamentals and Practices
- The Large Open Pit Project
- Deep Underground Instrumentation and Monitoring

The full texts are available in electronic version with the extended abstracts in print.

Priced at Indian Rs. 1500/US\$ 50 + Postage Charges, the proceedings would be very informative and useful reference to the concerned agencies/individuals. Members of CBIP and ISRM will be offered 10% discount. The proceedings can be purchased by payment through demand draft/cheque payable at par in New Delhi, in favour of “Central Board of Irrigation and Power”.

Manual on Rock Mechanics

The first Manual on Rock Mechanics, which was prepared under the guidance of an Expert Committee, was released by Central Board of Irrigation & Power (CBIP) in early 1979. The manual was very well received.

The manual was revised in 1988, to reflect the then state-of-art knowledge of Indian Engineers in the field of Rock Mechanics and contained 17 Chapters, covering basic concepts of Rock Mechanics, Field and Laboratory Tests on Rock Mass and Rock Specimen, Geophysical Investigations, Interpretation of Test Data and their Application to various problems of Foundation of Dams, Tunnelling, etc.

The Governing Council of the Indian National Group of ISRM felt that there was a need to update the manual, as more than 20 years had passed since its last publication.

Accordingly, the manual was updated and released during the ISRM International Symposium 2010 and 6th Asian Rock Mechanics Symposium held in New Delhi during 23-27 October 2010.

GUIDELINES FOR AUTHORS

The authors should submit their manuscript in MS-Word (2003/2007) in single column, double line spacing. The manuscript should be organized to have Title page, Abstract, Introduction, Material & Methods, Results & Discussion, Conclusion, and Acknowledgement. The manuscript should not exceed 16 pages in double line spacing.

Submission of Manuscript:

The manuscript must be submitted in doc and pdf to the Editor as an email attachment to **uday@cbip.org**. The author(s) should send a signed declaration form mentioning that, the matter embodied in the manuscript is original and copyrighted material used during the preparation of the manuscript has been duly acknowledged.

Peer Review Policy:

Review System: Every article is processed by a masked peer review of double blind or by three referees and edited accordingly before publication. The criteria used for the acceptance of article are: **contemporary relevance, updated literature, logical analysis, relevance to the global problem, sound methodology, contribution to knowledge and fairly good English.** Selection of articles will be purely based on the experts' views and opinion. Authors will be communicated within Two months from the date of receipt of the manuscript. The editorial office will endeavor to assist where necessary with English language editing but authors are hereby requested to seek local editing assistance as far as possible before submission. Papers with immediate relevance would be considered for early publication. The possible expectations will be in the case of occasional invited papers and editorials, or where a partial or entire issue is devoted to a special theme under the guidance of a *Guest Editor*.

The Editor may be reached at: uday@cbip.org

RECOGNITIONS



Dr. V.K. Singh, Chief Scientist & Head, Slope Stability Department, Central Institute of Mining and Fuel Research, Dhanbad, and an active life member Indian National Group of ISRM, has been awarded with **Society of Geoscientists and Allied Technologists (SGAT) Award of Excellence-2012**, in recognition of his outstanding contribution on Geotechnical Services to the Mining Industry for better management of safety and mineral conservation through eco-friendly mining.

Dr. V.K. Singh has been instrumental in confidence building to the civil construction projects in Himalayan Region and control of landslides. His prolific contribution towards development of indigenous technology and geotechnical contributions to Indian Mining Industry is praiseworthy.

His number of scientific publications in reputed international and national journals, different books on technology, has brought outstanding recognition to Dr. V.K. Singh as a true scientist in the field of earth science with special reference to geotechnical investigations and slope stability studies.

Dr. V.K. Singh has initiated, motivated and guided to establish geotechnical laboratories/slope stability cell in various mining organizations of repute in the country.

Indian National Group of ISRM congratulates Dr. V.K. Singh for his outstanding contribution to the Mining Industry, and wishes him to contribute more in future.

DR. BHANDARI AWARDED PRESTIGIOUS VARNES MEDAL FOR 2012



Dr R.K.Bhandari was awarded the prestigious Varnes Medal for the year 2012 at the UNESCO Headquarters in Paris on 23 November 2012 for excellence in research on Landslides. It is the highest award of the International Consortium of Landslides (ICL) and Dr. Bhandari is the first Indian recipient. The ICL represents 51 member institutions from 32 countries; and its International Programme on Landslides (IPL) was jointly established by UNESCO, WMO, FAO, UNISDR, UNU ICSU, IUGS and WFEO. Dr Bhandari is seen in the above picture with Professor Paolo Canuti, the President of ICL (extreme right), Professor Kyoji Sassa the Executive Director of ICL (extreme left) and Dr. Salvano Briceno, Chair of Science Committee of Integrated Research on Disaster Risk.

FORTHCOMING ACTIVITIES OF INDIAN NATIONAL GROUP OF ISRM

International Symposium “ROCK MECHANICS INDIA’ 2013 – PRESENT TECHNOLOGY AND FUTURE CHALLENGES” AND PRE-SYMPOSIUM WORKSHOP ON “OPEN PIT MINING” 3-5 JULY 2013, NEW DELHI, INDIA

INTRODUCTION

The study of rock mechanics has assumed considerable importance because of its wide application in civil engineering, more predominantly in water resources, mining engineering and underground structures. For the execution of multipurpose water resources projects located in complicated geological settings, the significance of rock mechanics in the design and construction was realised in late 1950s. Despite tremendous around advancement in technology, a full understanding of natural forces and phenomena eludes the design engineer. The details of the challenges encountered during construction of water resources projects in adverse geological conditions and the methodology/approach followed to reduce them have lot of significance to construction and design engineers. Similar experiences for the design and construction of road tunnels, metro tunnel, rail tunnels in complicated conditions along with stability of slopes will also be very useful. Mining is another field where besides open pit mining, deep seated ore mining is also providing challenges to engineers. Besides providing support, instrumentation is also gaining importance as it helps studying the moment of rock mass and provide timely warning to take appropriate action.

Both design and construction engineers would always be keen to know what advancements are taking place in their respective fields. Therefore, there is a need for up gradation of ones knowledge.

Liberalisation of economy has facilitated planning and execution of many exciting and complicated projects in India. These projects require application of modern principles of rock mechanics, which warrants deliberations and collaboration to facilitate flow of appropriate technology to enable successful implementation of such projects under a time-bound programme in a cost-effective manner, conforming to environmental requirements.

To deliberate on the advances in rock engineering, the Indian National Group of ISRM and the Central Board

of Irrigation & Power (CBIP) are organizing the present International Symposium – **Rock Mechanics India’ 2013** on “Present Technology and Future Challenges” and Pre-Symposium Workshop on “Open Pit Mining”.

SYMPOSIUM SUB-THEMES

1. Advancements in Testing and Characterisation of Rocks and Rock Masses
2. Modelling and Analysis of Rock Structures
3. Preservation and Restoration of Ancient Rock Monuments
4. Underground Construction and Mining in Problematic Geological Conditions
5. Utilisation of Underground Space including Storage of Water and Gas
6. Fracture and Fragmentation
7. Stability of Underground and Surface Openings
8. Environmental Issues
 - Special Session on Underground Mining
 - Underground Mining in Narrow and Wider Ore Bodies with Different Rock Mass Conditions
 - Underground Mining at Deep Seated Ore Body
 - Underground Development & Mining in Weak Rock Mass Conditions
 - Instrumentation in Underground Mining for Better Safety & Productivity

PRE-SYMPOSIUM WORKSHOP - OPEN PIT MINING

Topics proposed for discussions:

- Instrumentation and Slope Monitoring
- Pit Slope Stability in Open Cast Mines
- Blasting Practices for Safe Open Pit mining
- Groundwater Management

CALL FOR PAPERS / CASE STUDIES

Papers/Case studies on the topics proposed and allied topics are invited. The full text of the papers/case studies, **not exceeding 08 pages of A4 size**, in single space, both in MS Word and PDF, need to be sent through e-mail only at uday@cbip.org. **The last date for the receipt of full texts of the case studies is 15 June 2013.**

The papers/case studies will be reviewed by the Technical Committee as to their suitability for presentations. The papers/case studies accepted for presentations will be notified by 22 June 2013. A condition of acceptance of the papers/case studies will be that the author, or one of the authors in case of multiple authors, will attend the Symposium and make the presentation.

The paper/case study shall contain:

- a descriptive, but brief title
- title, name(s) and affiliation of the author(s)
- address for correspondence (including fax numbers and e-mail addresses)
- detailed information about the objective, methods, results and conclusion, to enable a correct appraisal of the suitability of the proposed paper/case study for the Symposium

Only original contributions that have not been published or presented at any other forum are acceptable.

REGISTRATION FEE

A. Pre-Symposium Workshop (3 July 2013)

Members of CBIP/ISRM/ITA/ICOLD/IGS	Indian Rs. 4,500/- USD 115 + Service Tax @ 12.36%
Non-Members	Indian Rs. 5,000/- USD 125 + Service Tax @ 12.36%
Researchers/ Academicians/ Students/ Accompanying Persons	Indian Rs. 2,500/- USD 65 + Service Tax @ 12.36%

B. Symposium (4-5 July 2013)

Members of CBIP/ ISRM/ ITA/ ICOLD/ IGS	Indian Rs. 9,000/- USD 225 + Service Tax @ 12.36%
Non-Members	Indian Rs. 10,000/- USD 250 + Service Tax @ 12.36%
Researchers/ Academicians/Students	Indian Rs. 5,000/- USD 125 + Service Tax @ 12.36%

C. Combined Fee for the Pre-Symposium Workshop and Symposium (3-5 July 2013)

Members of CBIP/ ISRM/ ITA/ ICOLD/IGS	Indian Rs. 12,000/- USD 300 + Service Tax @ 12.36%
Non-Members	Indian Rs. 13,500/- USD 340 + Service Tax @ 12.36%
Student/Accompanying Person	Indian Rs. 6,500/- USD 165+ Service Tax @ 12.36%

In case of 03 or more nominees from an organization, one nomination will be allowed free registration.

To avail the student concession in the registration fee, the registration form/request will have to be submitted along with a certificate from the head of the Department/ institute.

SYMPOSIUM SECRETARIAT

Central Board of Irrigation & Power

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ABOUT ISRM

The **International Society for Rock Mechanics (ISRM)** was founded in Salzburg in 1962 as a result of the enlargement of the “Salzburger Kreis”. Its foundation is mainly owed to Prof. Leopold Müller who acted as President of the Society till September 1966. The ISRM is a non-profit scientific association supported by the fees of the members and grants that do not impair its free action. The Society has 5,000 members and 46 National Groups.

The field of Rock Mechanics is taken to include all studies relative to the physical and mechanical behaviour of rocks and rock masses and the applications of this knowledge for the better understanding of geological processes and in the fields of Engineering.

The main objectives and purposes of the Society are:

- to encourage international collaboration and exchange of ideas and information between Rock Mechanics practitioners;
- to encourage teaching, research, and advancement of knowledge in Rock Mechanics;
- to promote high standards of professional practice among rock engineers so that civil, mining and petroleum engineering works might be safer, more economic and less disruptive to the environment.

The main activities carried out by the Society in order to achieve its objectives are:

- to hold International Congresses at intervals of four years;
- to sponsor International and Regional Symposia, organised by the National Groups the Society;
- to publish a News Journal to provide information about technology related to Rock Mechanics and up-to-date news on activities being carried out in the Rock Mechanics community;
- to operate Commissions for studying scientific and technical matters of concern to the Society;
- to award the Rocha medal for an outstanding doctoral thesis, every year, and the Müller award in recognition of distinguished contributions to the profession of Rock Mechanics and Rock Engineering, once every four years;
- to cooperate with other international scientific associations.

The Society is ruled by a **Council**, consisting of representatives of the **National Groups**, the **Board** and the Past Presidents. The current President is Prof. John A. Hudson, from United Kingdom.

The **ISRM Secretariat** has been headquartered in Lisbon, Portugal, at the *Laboratório Nacional de Engenharia Civil - LNEC* since 1966, date of the first ISRM Congress, when Prof. Manuel Rocha was elected as President of the Society.

BENEFITS TO MEMBERS

The current benefits given to ISRM members are:

- Individual and corresponding members

- 1 copy of the ISRM News Journal
- ISRM Newsletter
- Access to the members area in the website (download of Suggested Methods and Reports, Rock Mechanics lectures, videos, slide collection, etc.)
- Right to participate in the ISRM Commissions
- Registration with a 20% discount in the ISRM Congress, International and Regional Symposia and Specialised Conferences
- Personal subscription to the International Journal of Rock Mechanics and Mining Sciences at a discounted price (see details).
- Personal subscription to the Journal Rock Mechanics and Rock Engineering at a discounted price.
- Free download of up to 100 papers per year from the ISRM Digital Library at OnePetro: www.onepetro.org

- Corporate members

- Listed in the ISRM website, with a link to the company's website
- Listed in the ISRM News Journal
- Access to the members area in the ISRM website
- ISRM Newsletter
- 1 copy of the ISRM News Journal
- 1 registration with a 20% discount as ISRM member in the ISRM Congress, International and Regional Symposia and Specialised Conferences
- Free download of up to 250 papers per year from the ISRM Digital Library at OnePetro: www.onepetro.org

INDIAN NATIONAL GROUP OF ISRM

Introduction

The study of rock mechanics has assumed considerable importance because of its wide application in civil engineering, more predominantly in water resources, mining engineering and underground structures. For the execution of multipurpose water resources projects located in complicated geological settings, the significance of rock mechanics in the design and construction was realised in late 1950s. Despite tremendous advancement in technology, a full understanding of natural forces and phenomena eludes the design engineer. Liberalisation of economy has facilitated planning and execution of many exciting and complicated projects. These projects require application of modern principles of rock mechanics, which warrants deliberations and collaboration to facilitate flow of appropriate technology to enable successful implementation of such projects under a time-bound programme in a cost-effective manner, conforming to environmental requirements.

The Indian National Group of ISRM - ISRM (India) is involved in dissemination of information regarding rock mechanics, mining and tunnel engineering by organising symposia, seminars, workshops, and training courses, both at national as well as international level, in liaison with international organisations.

ISRM (India) represents International Society for Rock Mechanics, founded in Salzburg in 1962, as its Indian National Group.

Objectives

- to encourage collaboration and exchange of ideas and information between rock mechanics practitioners in the country
- to encourage teaching, research and advancement of knowledge in the rock mechanics
- to promote high standards of professional practice among rock engineers so that civil, mining and petroleum engineering works might be safer, more economic and less disruptive to the environment
- to hold events periodically on rock mechanics and rock engineering themes of general interest to the majority of the membership
- to cooperate with international bodies whose aims are complementary to those of the society
- to encourage the preparation of internationally recognized nomenclature, codes of practice, standard tests and procedures
- to encourage collaboration with and support of international programme in the field of Rock Mechanics including cooperation with other organizations in the activities of common interest
- to act as a coordinating National Body of International Society of Rock Mechanics, comprising of members in the country concerned with Rock Mechanics

Membership Fee

• Individual Membership for one calendar year:	Rs. 600.00
• Individual Membership for 10 calendar years:	Rs. 6,000.00
• Individual Membership for 20 calendar years:	Rs. 10,000.00
• Institutional Membership for 01 calendar year:	Rs. 10,000.00
• Institutional Membership for 02 calendar years:	Rs. 18,000.00
• Institutional Membership for 03 calendar years:	Rs. 25,000.00
• Institutional Membership for 05 calendar years:	Rs. 40,000.00

For membership and other details, please contact:

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Member Secretary

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